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ABSTRACT

An American Chemical Society (ACS) task force was charged to examine the state of chemistry education in the United States and to make recommendations in light of its findings. This document presents the task force's report and 39 major (and also secondary) recommendations. These recommendations, with accompanying discussions, focus on: (1) national concerns; (2) all levels of education; (3) elementary school science; (4) high school chemistry and science; (5) two-year college chemistry and chemical technology; (6) university and college chemistry and science; (7) careers in chemistry; and (8) industry and education. Comments on financial aspects and lists of recommendations arranged by target audience and principal agents (United States government; state agencies, curriculum bodies, and educational institutions; scientific societies, the chemical industry, and the ACS) are included. Among the highest priority recommendations are expanding the National Science Foundation and other federal programs to upgrade the quality of science instruction through direct service to teachers (addressed to the U.S. government), raising certification standards for elementary and secondary school science and mathematics teachers (addressed to state agencies and curriculum bodies), and expanding efforts to provide information on chemistry and chemical affairs to congressional and administrative decision-makers (addressed to the ACS). (JN)

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TOMORROW!

THE REPORT OF THE TASK FORCE FOR THE STUDY OF CHEMISTRY EDUCATION IN THE UNITED STATES

October 1984

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EXECUTIVE SUMMARY

The American Chemical Society Chemistry Education Task Force finds that:

Misunderstanding of science is widespread and the public understanding of chemistry is poor.

Too little science is taught in the elementary schools, possibly because too few teachers are well qualified to teach it. Neither programs to assist improvement of teacher qualifications nor good teaching materials are readily available.

Too few teachers of chemistry in high schools are well grounded in the subject; those that are are spread too thin, have too few mechanisms available for maintaining and improving their qualifications, and are too easily wooed away to more satisfying and more remunerative employment.

Laboratory exercises are slowly disappearing from general chemistry education in both high schools and colleges.

College chemistry for nonmajors has yet to find an appropriate character; that for majors is beset with unanswered questions about curriculum content, especially as it relates to future professional employment.

Applications of both information technology and discoveries about learning are occurring haphazardly.

Demand for—and supply of—well-educated chemists are poorly related to each other. Arbitrary barriers to entry and progress in the profession continue to be reported.

Industry does much to aid science education, but should do much more.

The highest priority recommendations of the Task Force are:

To the United States Government:

- Vigorous and large expansion of National Science Foundation and other Federal programs to upgrade the quality of science instruction through direct service to teachers.
- Establishment of Federally supported Regional Science Centers as focal points for improvement of precollege science education.

To State agencies and curriculum bodies:

- Raising of teacher certification standards in science and mathematics, in both elementary and secondary schools.
- Increase in the amount and level of science and mathematics taught to all students.
- Improvements of teacher compensation and in conditions of employment.

To Scientific Societies:

- Formation of a National Council on Education in Science and Technology to coordinate and oversee national educational efforts, with emphases on public understanding of science and on precollege education.

To the Chemical Industry:

- Strengthening and expansion of activities that bring the resources of the chemical industry to bear on improvement and support of science education at all levels.

To the American Chemical Society:

- Creation of a 5-year plan to improve chemistry education nationwide in the high schools.
- Consideration of how best to characterize opportunities in chemistry and the expectations of employers, identify necessary curriculum and resource elements, and utilize results of research to improve chemistry education.
- Expansion of efforts to provide information on chemistry and chemical affairs to Congressional and administrative decision-makers.

Grouped according to target entity, the principal recommendations of the Task Force are:

(N) With regard to National Concerns:

- Formation of a National Council on Education in Science and Technology to coordinate and oversee national educational efforts.
- Formation of a sub-Council on Public Understanding of Science and Technology.
- Formation of a sub-Council on Precollege Education in Science and Technology.
- Strong ACS participation in these efforts.

(A) With regard to All Levels of Education:

- Vigorous and large expansion of National Science Foundation and other Federal programs to upgrade the quality of science instruction through direct service to teachers.
- Expansion of Federal support of research and development in the use of computers and other information technologies in science education.
- Expansion of Federal support of research in science education.

(E) With regard to Elementary School Science:

- Coordinated effort by scientific and engineering societies to address the major problems of science education in the elementary schools.
- An immediate national effort by scientific and engineering societies to add science to the present basic triad of school subjects.
- Development of model science programs for each grade level K-8.
- Development of guidelines for certification of elementary school teachers to teach science.
- Establishment of Federally-supported Regional Science Centers as focal points for improvement of precollege science education.
- Expansion of ACS activities in the area of pre-high school chemistry education.

(H) With regard to High School Chemistry and Science:

- Creation of an ACS 5-year plan to improve chemistry education nationwide in the high schools.
- A national effort to raise teacher certification standards in science and mathematics and to secure adherence to such standards.
- Adoption of a national minimum standard that 3 years of science taught with laboratory and 3 years of mathematics be required for graduation from high school.
- Study of changes necessary to improve the high school chemistry curriculum.
- Adoption of a guideline that at least 30 percent of class time be devoted to laboratory exercises in the high school chemistry curriculum.

(T) With regard to Two-Year College Chemistry and Chemical Technology:

- Revision of the ACS 1970 "Guidelines for Chemistry in the Two-Year Colleges."
- Development by ACS of an outreach and consultation program to assist improvement of chemistry programs in two-year colleges.
- Establishment of an ACS approval service for Chemical Technology programs.
- Development of an ACS approval service for college transfer and other two-year college chemistry programs.

(U) With regard to University and College Chemistry and Science:

- National effort to attain acceptance of a requirement for admission to colleges and universities of at least 3 years of laboratory science and 3 years of mathematics taken in grades 9–12.
- National effort to assure that the laboratory science requirement for any baccalaureate degree is at least 10 percent of the undergraduate credit that must be earned by the student.
- Establishment of guidelines to the appropriate balance in college-level chemistry courses for nonscience majors among the fundamental principles of chemistry, applications of chemistry, and the place and role of the chemical sciences in contemporary society.
- Development of a program of workshops and other activities to increase interaction among teachers of the natural sciences and engineering, the arts, humanities, and the social sciences.
- Adoption of a standard that all college-level foundational chemistry courses, whatever their student clientele, include substantial and significant laboratory work.
- Preparation by the ACS Committee on Professional Training of recommendations concerning the content of chemistry courses intended for students who are not majors in chemistry.
- Development by ACS of curriculum modules in such aspects of chemistry as are germane to the curricula of professional schools of law, business, and the health professions, among others.
- Inclusion in the budgets of instrument purchase programs of additional funds to permit development of cooperative mechanisms for the maintenance and repair of such equipment.
- Sponsorship by the ACS of the preparation of position papers providing advice and guidance to faculty members on ways to include or improve instruction in the undergraduate curriculum on a number of specific topics and areas.
- ACS consideration of how best to characterize opportunities in chemistry and the expectations of employers, identify necessary curriculum and resource elements, and utilize results of research to improve chemistry education
- Consideration of the mission of the ACS Committee on Professional Training.
- ACS leadership of efforts to modernize the concept and structure of technical libraries.

(C) With regard to Careers in Chemistry:

- Government and industrial support of a program of postdoctoral appointments for research on problems of national concern to assist bridging temporary differences in employment demand and scientist supply.
- ACS sponsorship of efforts to identify and correct arbitrary restraints on women, minorities, and other special segments preparing for or practicing the profession of chemistry.
- Increased development, testing, and evaluation of electro-optical systems for continuing education; expansion of ACS continuing education services.

(I) With regard to Industry and Education

- Strengthening and expansion of activities that bring the resources of the chemical industry to bear on improvement and support of science education at all levels.
- Establishment of an ACS staff Office to deal with activities at the academic-industrial interface.

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PREFACE

The American Chemical Society Chemistry Education Task Force was appointed in January 1983 by the then-Chair of the Society Committee on Education, Dr. Stanley Kirschner, and began work almost immediately.

The charge to the Task Force was a simple one: *Examine the state of chemistry education in the United States today and make such recommendations for action as seem appropriate in light of the findings.* We determined to look at all levels of education and at both formal and informal modes; we did not feel that we were directed to be practical or even reasonable.

While the funding of the Task Force's work was generous, it was not lavish. It was realized early that surveys over the various parts of the national educational apparatus, of students and other consumer groups, and even of the smaller collection of persons who have thought and are thinking deeply and conscientiously about education in the sciences, were not possible. Rather, the Task Force decided to use as leverage for its experience and as the starting point for its thinking the substantial and growing collection of reports published recently (some of the most important being issued during the active work period of the Task Force) by several bodies national in scope, by a myriad of groups more limited in compass, and by informed and concerned individuals.

Among the first are the reports of The National Commission on Excellence in Education (April 1983) and The National Science Board Commission on Precollege Education in Mathematics, Science and Technology, and many reports of conferences and other studies of problems in chemistry education done under the auspices of the American Chemical Society. Complete listings of these source materials will be found in the Bibliography.

Members of the Task Force made no secret of their work and information flowed freely to us. As the program of working meetings was followed, a number of invitations were extended to interested persons to provide opinion, expressions of concern, proposals for the solution of perceived problems, etc. Later, when the recommendations of the Task Force were in preliminary form, several hundred persons were asked to comment on that part of the Task Force work product. Finally, drafts of this report were sent to a small number of very knowledgeable individuals for critical review.

The Task Force has identified some serious problems in science education and in chemistry education, and recommendations are made for action to improve such problem situations. Not all of the identifications or recommendations are entirely original with this Task Force—we are far from the only persons addressing these matters in a formal, organized fashion. Our debt to the efforts of other groups and individuals is substantial. Perhaps if the number, scope, and concern of such mutually indebted endeavors grows sufficiently, something will be done to allocate human, fiscal, and physical resources to the solution of the problems.

INTRODUCTION

Any study of the state of chemistry education must begin with a look at the whole of which chemistry education is a part.

Enrollment fluctuations notwithstanding, education in the United States is a huge enterprise. Currently, the elementary schools enroll 27 million students, high schools 14 million, and colleges and universities over 12 million. There are about 100 thousand precollege institutions and they employ 2.5 million teachers; the 3300 college-level institutions have 620 thousand faculty members. The leverage of such large numbers is enormous: if every high school student were given the opportunity to perform a precipitation test for aqueous chloride ion by using one milliliter of tenth molar silver nitrate solution, the reagent cost would be over $80,000.

The current budget of the U.S. Department of Education is about $14 billion; the aggregate of annual state, Federal, and municipal expenditures on education (much of it for instruction) has been estimated at $150 billion, about half as large as the budget of the Department of Defense. Average annual expenditures per pupil are about $2000 in the schools, over $3000 in two-year colleges, and over $9000 in four-year colleges and universities.

Science and mathematics education starts early in the elementary schools. For grades K-3, 17 minutes per day are devoted to science, 41 to mathematics, and 95 to reading; in grades 4–6, science gets 28 minutes per day, mathematics 51, and reading 66. Elementary school students maintain more positive attitudes toward mathematics than toward school in general, but there is a steady decline in such affection as the grade level increases; the trend is reversed for science. Forty-eight percent of nine-year olds identify mathematics as their favorite subject, 6 percent choose science; among seventeen-year olds, mathematics is the favorite subject of 18 percent, science of 12 percent. Unfortunately, student achievement in both science and mathematics has declined steadily at all age levels during the last 15 years.

Nationwide, there has been a steady decrease in the amount of science completed by students during the high school years. In the decade ending in 1981, students completing more than two years of science in grades 10–12 declined from 31 to 25 percent of high school seniors. The trend is similar among college-bound high school seniors, though they included more science in their programs than did other students; the median number of years of courses completed in grades 7–12 by the college-bound group was: 4.2 years of English, 3.7 of social sciences, 3.5 of mathematics, 1.3 of biological science, and 1.6 of physical sciences, in 1980–81.

In 1980–81, about 2.8 million students graduated from high schools and about 1.5 million of them went on to some higher education. Their potential may have been somewhat lower than that of the corresponding group of students seeking college admission in 1966–67: in those fourteen years, the average score on the Verbal part of the Scholastic Aptitude Test (SAT) declined from 467 to 425, on the Mathematics part from 494 to 468.

The division of the stream of students entering colleges and universities into employment interest groups, and therefore into majors or fields of concentration, occurs early, and there have been some marked changes in the last decade or so. In 1970, 19 percent of college freshmen indicated precollege teaching as a probable career (11 percent pointed toward the secondary schools) and 2.5 percent one of the physical sciences; by 1982 these indications became 5 percent (2 percent) and 2.8 percent, respectively. The average Verbal SAT scores of intended education majors fell from 418 to 391 in this period, that on the Mathematics part from 449 to 418. The corresponding figures for intended majors in a physical science changed more: average Verbal SAT fell from 515 to 438, average Mathematics SAT from 580 to 520.

Colleges and universities awarded (all fields) 420 thousand associate degrees in 1980–81, 940 thousand baccalaureates, 360 thousand masters, and 40 thousand doctorates. In education there were 108 thousand bachelor degrees awarded in 1980–81 (down from 194 thousand in 1972–73), 99 thousand masters (down from a historic high of 128 thousand in 1975–76), and 7 thousand doctorates (a rate essentially unchanged for over a decade). In physical science education, baccalaureate degrees fell from 900 in 1970–71 to 600 in 1980–81, masters from 800 to 500, and doctorates from 90 to 80; in mathematics education the decline was steeper: baccalaureate degrees fell from 2200 in 1970–71 to 800 in 1980–81, masters from 800 to 400, and doctorates from 50 to 30.

There have been declines in degree production in the physical sciences, including chemistry,

in this period, but they have been much less—averaging about 10 percent at any level. In 1980–81, for example, there were some 10 thousand baccalaureate degrees awarded in chemistry, 1800 masters, and 1600 doctorates; the corresponding figures for all physical sciences were 21 thousand, 5.5 thousand, and 3600, respectively.

By 1980–81 the proportion of graduating certifiable teachers in mathematics who did not apply for school teaching positions had reached 27 percent; the figure for physical science certifiable teachers was higher. In 1980–81, of the individuals teaching primarily mathematics and/or science, 87 percent were certifiable in some field—but only 44 percent in the field in which they were teaching.

College and university chemistry faculty members are clearly undercompensated in comparison with their colleagues in industry, and the steady decline in student interest in rigorous fields has not helped their esprit. But their problems of image, morale, and compensation are trivial in comparison with those of teachers in the elementary and secondary schools.

Favorable attitudes toward their careers by teachers in schools decreased dramatically in both intensity and frequency of occurrence during the past two decades. Teacher morale appears to have been affected more adversely by factors such as changing public attitudes toward the schools and teachers, media treatment of the institutions and the profession, and student attitudes toward learning, than by concerns over inadequate teacher compensation. Even student behavior and class size are rated by teachers as less important cause agents for career-related dissatisfaction than the attitudes of others about the profession.

Not that there are not real problems of facilities and finance in the schools generally. Science teachers have greater need than others for special kinds of facilities and equipment, costly materials for instruction, smoothly functioning supply systems, and safe space. Seldom are these forthcoming in the quantity or quality needed.

Teachers feel real pressures born of student interest in science and the relentless change of the discipline. Only about a quarter of elementary school teachers are confident of their ability to teach what science there is in the curriculum at that level. A somewhat smaller proportion (but still over an eighth) of secondary school teachers of science admit to feeling inadequately qualified to teach one or more of their courses. The interest of high school science teachers in improving their qualifications is well evidenced by the fact that by 1977 forty-seven percent of them had attended one or more of the institutes sponsored by the National Science Foundation; unfortunately, attrition in the profession and the demise of that program have lowered this fraction substantially.

What is the state of chemistry education in the United States today? Chemistry as such is ordinarily a high school and college subject, though there is some chemistry content in the science taught in the elementary schools. Nearly everywhere one finds evidence of student, teacher, and parent interest in science as a school subject. In many places one finds that this interest can be demonstrated in terms of good teaching, sound student achievement, and strong parental and community support for the programs and facilities necessary if sound instruction is to be given. In many places one finds examples of dedication, commitment, and determination. But, those places are rather scattered. The fraction of the students at any grade level who learn in an environment as positive as that reflected above is quite small—too small for good service to the future of either the students or the Nation.

At too many places, at too many levels, teachers are ill-qualified to teach science. Elementary school teachers often have had no serious science instruction in their preparation for the profession. At the high school level, few who teach chemistry have real subject matter competence in the discipline, and those who do are increasingly easily wooed away to other professional employment. In both the high schools and in smaller colleges, too many faculty members are forced into an instructional pentathlon—spread thin over far too many different assignments for quality performance in any of them. There is very little organized help for teachers at any level who want to maintain or improve their competence to give instruction in a science discipline, chemistry included.

Curriculum materials of high quality and demonstrable effectiveness do not exist in profusion; the lower the grade level the greater the need. Marketing forces push instructional materials toward conformity and uniformity, with the predictable result that neither diversity nor excellence is found or served. The computer, instead of liberating instruction, threatens to put it into a straitjacket—conveying subtly, for example, the false notion that science is all known and closed instead of exploratory and open-ended. Laboratory exercises, in part because they are logistically difficult and have always been expensive, are being seen more and more often as unnecessary—students are expected to learn from watching someone else's "hands on" instead of their own.

Colleges and universities have similar problems. Chemistry is a neglected "liberal art"; neither admission nor graduation requirements reflect its place or value in contemporary life, or its intellectual worth. Pressures for efficiency drive curricula toward single approaches to chemistry in spite of the diversity of student interests and capacities. There is complaint that chemists isolate

themselves from meaningful interaction with their faculty peers in other fields, both science and nonscience, which depend on chemistry for service instruction. Many questions are raised about the content, currency, and relevance of the undergraduate preprofessional chemistry curriculum in regard to the career goals of individuals and the broad spectrum of employment opportunities afforded its graduates. Some assert that there is a serious mismatch between the legitimate expectations of those who employ chemists and the assumptions of those who devise and implement the curricula which prepare them for employment. In some areas, e.g. information science as applied to the practice of chemistry, industries report that they cannot rely on their new employees being adequately prepared. Poor funding of higher education is moving the cutting edge away from higher education toward industrial laboratories, which seem to be able to keep their instruments on line. Learning in chemistry must be lifelong, but continuing professional education is accorded much less attention than it deserves.

There are still other kinds of problems at the academic-industrial interface. Industry does much for education, but only a fraction of what would be desirable in its own long-term interest; this is especially true where the public understanding of science is concerned—with chemistry and industry a very sensitive area. Industries do little to exchange information about any good and effective programs that they have in education; and they do even less to communicate such tidings to the public. Industry also hears a different drummer than does the educational system that produces its scientists; as a result, industrial demand for chemists, for example, can change ten times as rapidly as the educational system and students can respond. And, in both industry and academe, women, minorities, and the handicapped continue to report artificial barriers to the progress of their careers.

The conclusions drawn from these findings by the Chemistry Education Task Force take the form of thirty-nine principal recommendations and numerous ancillary ones, all set forth in the sections which follow. We begin with recommendations (N) that reflect our concern for the nationwide low level of public understanding of science, and our conviction that the momentum generated by recent national studies of school education, in general, and of education in mathematics, science, and technology, in particular, must be maintained. There follow some proposals (A) that relate to education at all levels. These are, in turn, followed by clusters which deal with problems at the levels of the elementary schools (E), high schools (H), two-year colleges (T), and colleges and universities (U). Sections dealing with matters related to the careers of some chemists (C), including continuing education, and with the special opportunity we believe exists for the chemical industry (I), complete the Report.

At the start, the Task Force was advised to concentrate its attention on post-secondary chemistry education, with special emphases on the undergraduate and graduate preparation of chemical scientists and on their continuing professional education. Soon, however, many urged us to broaden the scope of the study, expressing the conviction that the education of nonscientists and critical problems in precollege education were equally deserving of our efforts—that the whole of chemistry education should be looked at. We took the latter advice.

The recommendations of the Task Force reflect disquiet with precollege education in many respects, not just with instruction in chemistry or in science. Our disquiet is somewhat closer to alarm than our prose may suggest. The quantity of precollege education is great, but too often its quality is not. Much of the time we expect the wrong things of our system of education and employ poor tactics that evolve into worse strategy: to avoid discrimination *against*, we have thrown away discrimination *for*; to avoid barriers, we have thrown away hurdles; in pursuit of fun and happiness, we have praised effort but reduced challenge and depreciated achievement; we decry the falling test scores of students—but it is we who are weighed in the balance and found wanting.

Though we are deeply troubled by the problems of- and facing-chemistry education today, we are optimistic that the people will sense the hazard and support the changes that must be made. That would be consistent with the American character, no better described than by Alexis de Toqueville:

> "They [the Americans] have all a lively faith in the perfectibility of man, they judge that the diffusion of knowledge must necessarily be advantageous and the consequences of ignorance fatal; they all consider society as a body in a state of improvement, humanity as a changing scene, in which nothing is, or ought to be permanent; and they admit that what appears to them today to be good, may be superseded by something better tomorrow."

The Task Force trusts that that spirit continues to the present day.

We believe that education and disciplined learning, that provided a substantial base on which our society was founded, are critical to its survival. The study of the universe and of the creatures that occupy it are among humanity's noblest efforts and achievements. But, while such study has increased in depth and penetration, and its results have been used to change our lives at an

ever increasing rate, education in science and technical fields has weakened and fallen behind the pace of applications. This situation may have existed always—but the disparity has become intense and critical in the last twenty years.

We believe that there are effective means that can be employed to restore the educational system to a viable state where it can serve more effectively the noble purposes we ascribe to it, but those means must be employed in an orderly fashion and consistently over a substantial period of time; we do not believe that a crash program can overcome the losses of past years in short order.

Such efforts will require a rededication of many individuals and units of our society to the goals and purposes of education. This rededication cannot be achieved in time now considered spare, or excess over an individual's normal duties, but must be part of those normal duties. Since the time and effort of individuals are equivalent to financial resources of the community, substantial redirection of the use of those resources is in order, and, indeed, without such reallocation no progress will be made toward the desired long-term changes in the educational Establishment.

Thus, we call for redirection of the assets of time, money, and other capital of our civil and professional societies. We call upon the American Chemical Society to establish certain bodies, task forces, and staff offices to undertake certain studies and projects which we believe will prove healthful. We call upon the chemical industry for resources to sustain the educational programs on which its own future must depend. Above all, we call upon the State and Federal Governments to devote resources they derive from the society they administer to the sustenance of the future of that society through improved education.

Recommendations on NATIONAL CONCERNS

N1 National Council on Education in Science and Technology
N2 Sub-Council/Commission on Public Understanding of Science Technology
N3 Sub-Council/Commission on Precollege Education in Science and Technology
N4 Chemistry Literacy and the American Chemical Society

Photo: National Aeronautics and Space Administration

The public about whose understanding we are concerned is, in fact, all publics—the educated and uneducated in science, the voter and the politician, the child and the adult . . .

N1: NATIONAL COUNCIL ON EDUCATION IN SCIENCE AND TECHNOLOGY

Recommendation: Formation of a National Council on Education in Science and Technology to coordinate and oversee national educational efforts.

There is deep concern about the impact of science on the "conditions of men," and growing anxiety that genetic science may affect the "sorts of men." How we react to these realities depends at least in part on what is commonly termed the *public understanding of science*; how that understanding came to be and what it might be in the future depend on the ongoing processes and content of *education in science and technology*. We believe that these two are inextricably bound up with each other.

Effective communication is a basic personal need. It is also a critical societal need. In both domains, the first prerequisite is common understanding. It is no longer arguable that effective communication about science between important sectors of the population is in a state of collapse. Neither science nor technologies based on it seem likely to wane in their significance to the national life and welfare. If decisions relating to that significance are to be made democratically and wisely, steps must be taken to improve the general, the public understanding of science.

Understanding of science has many levels and dimensions: for example: (1) understanding of what science is, and what it is not, including some knowledge of the scientific approach to matters known and unknown; (2) knowledge of some of the basic elements of science, including some of the fundamental scientific constructs; (3) the ability to function effectively as a citizen in the contemporary technical environment; and (4) knowledge of "organized" science—e.g. basic science, applied science, and development—and information about the impact of science on the individual and on society through decision-making and policy formation.

The *public* about whose understanding we are concerned is, in fact, all publics—the educated and the uneducated in science, the voter and the politician, the child and the adult—because they, in various ways, comprise the four strata into which issues divide a population: the decision-makers, the policy makers, the attentive (and, one hopes, informed) public, and the non-attentive (and, one fears, ill- or mis-informed) public.

Any benefits that accrue to society and any hazards to which it is exposed because of the uses to which science is put will depend on value judgements made by the public or in its name: by citizens-voters, by public representatives whom they elect, or by public officials whom they permit to be appointed. These value judgements can be no better than the capacity of the judgement maker to understand and weigh the consequences of what are sometimes manifold and complex scientific and technical options. This is the public policy dimension of the public understanding of science.

There are other dimensions of the public understanding of science; a major one is economic. Contemporary society is based increasingly on the fruits of scientific and technical discovery and endeavor. The world around us is changing at least as rapidly as ever before and in easily discernible ways. Both the quality and quantity of the national life depend on the adaptive capacity of the people, and that capacity is undesirably low in science-based areas. The risks are that necessary adaptation will be impressed on those who cannot understand and change, and that thereby the general interest will not be served. It is critical to our national life that there be wide, informed, and intelligent participation in the determination of public issues. The need in areas related to science is at least as great as that in any other.

Whatever is the quality of the present public understanding of science, it will be affected not only by what is done to improve it directly, but by what the understanding and sophistication are of young people who join the adult public as they complete their education. It is important that a capable and credible voice be developed which can speak to government, to the academy, to industry, and to the people in effective ways about the quality and quantity of education in the schools for citizens *and* about the preparation received there by students who will go on to more advanced education in science or a science-related field.

N1. A National Council on Education in Science and Technology should be formed to coordinate and oversee educational efforts at all levels in science and technology—both for the general education of the population and for the practice of such specialties. In recognition of the size and complexity of the task of improving education in science and understanding of it, two sub-Councils should be formed to deal with: (1) the public understanding of science and technology; (2) pre-college education in science and technology.

a. The proposed National Council, if not created and supported by an appropriate office or officer of the United States Government, should be founded by representatives of the major scientific and technical societies and, at least initially, funded by them.

b. Such a National Council should be a pan-scientific body. Ways might have to be developed early to control its size, lest it become a "congress" unwieldly in numbers, but the National Council membership should include representation from scientific discipline societies (e.g. American Chemical Society, American Physical Society), disciplinary area organizations (e.g. American Institute of Biological Sciences), pan-scientific organizations (e.g. American Association for the Advancement of Science), science teaching associations (e.g. National Science Teachers Association, American Association of Physics Teachers), among others. It is important that the Council be representative, so that the interpenetration and interdependence of the various technical disciplines be turned to advantage and that articulation be improved.

c. The Council should stimulate, study, coordinate, and oversee policy development and activities concerned with: (1) the public understanding of science and technology and of their interactions with society; (2) the improvement of the science and the science-related components of precollege education.

In later sections of this Report, this Task Force proposes a number of responsibilities for the National Council in less global terms. At those points appropriate detail will be given of suggested approaches and structures. Here we emphasize the *national* and *council* aspects. A similar council with somewhat broader responsibilities was proposed by The National Science Board Commission on Precollege Education in Mathematics, Science, and Technology.

N2: SUB-COUNCIL/COMMISSION ON PUBLIC UNDERSTANDING OF SCIENCE/TECHNOLOGY

Recommendation: Formation of a sub-Council on Public Understanding of Science and Technology.

The preceding section proposes a national council that would coordinate the public and professional aspects of education in science and technology through two sub-councils—one devoted to the work of the formal educational system, the other devoted to the processes of communication to and education of the general public. Presumably, the council and the sub-councils would be created in the same way.

Science is popular fare these days; witness the rapid increase during the last two years in the number of periodicals devoted to bringing to a presumably numerous and widespread audience sound writing and pictorialization of the progress of science in many areas; witness the significant and steady increase in the number of television programs devoted to scientific subjects. Yet one wonders if the speech from those pulpits is not sermons to the committed. The understanding of science that languishes today is not that of the educated or attentive citizen whose interest has already been gained, it is that of the unaware, inattentive citizen who has not been engaged.

There has been substantial interdisciplinary cooperation in a number of efforts to improve the public understanding of science and the impact of science and technology on society and the human condition. Such activities have involved elements of the media, industrial, institutional, educational, and scientific Establishments with little or no coordination. While one would not wish to place a heavy controlling hand on such efforts, one might well hope to improve their efficiency and effectiveness by fostering their coordination.

In part, concern that the public understanding of science and technology is not as good as it should be arises in the belief by science-literate persons that the quality of public participation in the making of science-related decisions is poor: non-science is not distinguished from good science; the unscientific masquerades too easily as supportable and true; the declared absolute is heard and respected while the never-completely-certain reality is unwanted and rejected. The science-literate see in these signs the possibility of stampede instead of sound judgement in the development of solutions to those problems of society that relate to or derive from science and technology.

N2. Whether or not a National Council is formed, the equivalent of its sub-Council or Commission on Public Understanding of Science and Technology must be formed. This body should provide stimulation, study, coordination, and evaluation of a wide variety of activities designed to improve and advance the public understanding; it should be an advocate for a needed change.

a. Such a sub-Council or Commission should include not only representation from the several domains of professional science [scientific discipline societies, disciplinary area organizations, pan-scientific organizations, science teaching associations, and others], but membership drawn from the information community [media experts (print and electro-optical), communications organizations (e.g. American Museum Association, National Association of Science Writers, American Library Association, Corporation for Public Broadcasting), etc.], major support agencies [National Science Foundation, Department of Education, the private foundations, and others], and major industries and industrial organizations.

b. The initial responsibilities of this sub-Council or Commission should include: (a) working with the National Science Foundation and the National Assessment of Education Progress to establish programs for measuring the national, regional, and perhaps even state levels of public understanding of science; (b) working with various groups to develop a system for collecting and reporting information on the public understanding of science and technology; (c) developing programs for evaluating and reporting on the total national effort on communication of science and technology to the public and the related improvement in public understanding. In addition, this sub-Council or Commission might: (d) sponsor or convene national and regional conferences on various aspects of communicating science to the public; (e) sponsor the establishment of a National Center for Public Understanding of Science which would serve as a stimulating focus for research and development of a multi-disciplinary character.

N3: SUB-COUNCIL/COMMISSION ON PRECOLLEGE EDUCATION IN SCIENCE AND TECHNOLOGY

Recommendation: Formation of a Sub-Council on Precollege Education in Science and Technology.

No nation has turned so consistently, so forcefully, and so broadly to education to prepare its people for informed participation in democratic processes as has our own, nor is it likely that that reliance will diminish in the future. The present widespread mis- and dis-understanding of science is due in part to the rapid expansion of scientific knowledge and to the acceleration in the rate at which new knowledge is applied to the things and matters of everyday life. But, it is also due to the failure of the processes and (likely) the Establishment of education to keep pace with that expansion and acceleration. It is fruitless to attempt to fix blame for the present situation. The more important task by far is to restore health to the public understanding of science, and attention to education is a major portion of that task.

Complex modern society demands that science and technology be both used and understood. The same educational apparatus that provides the underpinning for the general and public understanding of science is responsible also for the early schooling of those who will progress from the learning to the "doing" of science—to the discovery of knowledge that later will be put to use.

The concern of the people for the state of the nation's schools and the educational tasks they are supposed to accomplish has led to the formation of a number of bodies charged to study the national system of precollege education and report their findings, plans, and recommendations for action. Foremost among such bodies are The National Commission on Excellence in Education and The National Science Board Commission on Precollege Education in Mathematics, Science and Technology, both of which issued extensive reports in 1983. As will be seen later, the recommendations of this Task Force echo and build in many ways on the findings and proposals of those two Commissions. We believe that the needs they have identified must be addressed, that the tasks they have set must be accomplished, and that the momentum of their efforts must not only not be lost—it must be translated into continuing oversight of the state of the nation's efforts and progress in science, mathematics, and technology education.

N3. Whether or not a National Council is formed, the equivalent of its sub-Council or Commission on Precollege Education in Science and Technology must be formed. This body should provide continuing oversight and evaluation of a wide variety of activities designed to improve and strengthen precollege education in science, and technology; it should be an advocate for needed change.

a. Since this body is intended to both inherit the mantles and to continue bearing the burdens of the

National Commission on Excellence in Education and The National Science Board Commission on Precollege Education in Mathematics, Science and Technology in the areas of science and technology, at least, it is best that its composition reflect theirs, with appropriate additional emphasis on expertise from the several technical disciplines.

b. The initial responsibilities of this sub-Council or Commission should include: (a) working with the National Science Foundation and the Department of Education to develop Federal, state, and local support for efforts to improve the qualifications of present teachers; (b) working with Federal, regional, and state education agencies, and with the professional technical and teacher organizations, to coordinate and improve present systems for assessing the quality of precollege education in science, mathematics, and technology; (c) developing programs for evaluating and reporting on the total national effort to improve and strengthen precollege education in science (including mathematics) and technology.

Virtually every individual or group that has reported a recent study of the problems in science education has proposed the formation of a national body to spearhead improvements. While agreeing that the Federal Government will play a central role in such efforts, the several studies have proposed different compositions, authorities, and placements with respect to the Government of this national leading body.

A major recommendation of *The National Science Board Commission on Precollege Education in Mathematics, Science and Technology* is that the President of the United States appoint immediately a "National Education Council made up of representatives from a cross-section of national interests." This Council would "provide leadership in developing, coordinating and implementing plans to improve and maintain the quality of the Nation's elementary and secondary education in mathematics, science, and technology."

On a continuing basis, the National Education Council would "identify educational goals and recommend the changes needed in the form and content of education to reach these goals; ensure that (an) assessment mechanism . . . is developed and maintained for measuring and comparing student achievement, participation and progress toward these goals in every state, school district and school; . . . monitor and report anually to the American people on the status of American education and progress toward achieving these educational goals . . . facilitate the sharing of information about successful mathematics, science, and technology educational programs . . . and recommend incentives to encourage state, local and private investment in education."

[The Commission recommended annual appropriations of $2.75 million to support the Council and $5 million to finance the assessment mechanism.]

The National Council that this Task Force has proposed differs from that described by the NSB Commission in two principal respects: ours would be an independent body rather than a unit of the Executive Branch; and, its responsibilities would include both precollege education and the more diffuse matter of the public understanding of science.

A distinct advantage of the Commission's proposed Council is that it *could* be given real coordinating authority extending beyond what are essentially advisory roles—and such authority may be important if Federal support is to be deployed with maximum effectiveness. An important strength of the Council we propose is that it would deal with the understanding of science by present citizens as well as future ones.

The National Science Foundation and the Department of Education are the Federal Agencies with major capacities and/or programs in what might be termed civil science education. There have always been a certain amount of tension between the two over their respective roles. Those who believe that the National Science Foundation should support programs as close as possible to the research frontier have opposed its high school (and sometimes college) teacher education activities in mathematics and science, preferring that the Department of Education be the responsible agency; similar preference has been expressed by those who see nothing special about science and mathematics as school subjects.

This Task Force agrees with the NSB Commission that the National Science Foundation "has recognized expertise in curriculum development," and that its summer inservice institutes "provide a proven model for the upgrading of teacher skills." The National Science Foundation can draw upon the ingenuity and resources of the scientific community to solve problems in science education; further, it has been very successful in strengthening the competence of teachers whose duties are centered strongly on disciplinary subject matter—i.e., college and high school faculty members.

On the other hand, the Department of Education is much more practiced in reaching the vastly greater number of elementary, middle, and junior high school teachers, whose duties are usually more diverse and whose professional preparation is less strongly focussed—and, as we will note later, may be very deficient in science content.

To coordinate science education-science educator activities of the National Science Foundation and the Department of Education, a *National Science Education Board* could be created within the Executive Branch of the United States Government as an interagency unit; in addition, such a Board could play the informed conscience role envisioned by the NSB Commission. It could easily, "identify, recommend, monitor, and report," but it

would be very difficult for such a body to "facilitate and ensure" unless it had additional authorities (suggested in Recommendations N1–N3) to "study, stimulate, oversee, evaluate, *and coordinate*."

To the degree that its powers would depend ultimately on control over the purse, a National Science Education Board would have to have authority to direct and coordinate those fractions of their annual appropriations that NSF and DOE are authorized to expend on science education. And, in that sense, it would be an operational as well as an advisory body. A National Science Education Board so situated and so empowered could be a highly effective spearhead for the many activities envisioned for its counterpart by the NSB Commission, and it could play a strong intiating and directing role with respect to the numerous teacher, curriculum, and instructional materials improvement activities described in later sections of this Report.

N4: CHEMISTRY LITERACY AND THE AMERICAN CHEMICAL SOCIETY

Recommendation: Strong ACS participation in these efforts.

Physicists have expressed concern over the "mad scientist" image of them that is frequently projected by the media; and, justifiably, chemists are tired of their image as despoilers of the world. The public is very much aware that "chemicals" pollute some portions of the environment, and very little aware that their lives are chemical. The public is caught up with the potential of genetic manipulation for improvements in human health and crop yields, but does not know that genetic "engineering" *is chemistry*—pure and not-so-simple. The content and balance of the chemistry component of the science literacy of the general population need attention.

The American Chemical Society budgets several hundreds of thousands of dollars annually for activities designed to improve the public understanding of science in general and chemistry in particular. The Council Committee on Public Relations, Joint Board-Council Committee on Chemistry and Public Affairs, and Board Committee on Public Affairs and Public Relations have important oversight responsibilities. The Education Division, Department of Public Affairs, and the Office of Public Relations, all three of which are staff activities, mount numerous programs that seek to improve aspects of public understanding. And several member groups, such as Corporation Associates and the Division of Chemical Education, are vigorously active in the area.

This Task Force believes that there is at present too little coordination of the Society's activities designed to improve the public understanding of chemistry. Public-oriented and education-oriented efforts interpenetrate each other, but there is little reflection of this reality in the way the Society's programs operate.

N4. Within the American Chemical Society, a committee or task force (perhaps ad hoc) on public understanding of chemistry should be formed to: (a) provide the input for chemistry to the proposed National Council (N1) and its suggested sub-Council or Commission on Public Understanding (N2); (b) provide coordination and oversight of ACS activities in this area; and (c) establish a sub-unit to give needed attention to the implementation of the Society's educational efforts directed to non-scientists.

a. This Task Force believes that the American Chemical Society should place additional emphasis on its activities as a direct interpreter and adviser to Congressional and administrative decision-makers, and that it should expand its efforts to provide information to interpreters and popularizers of science. An appropriate ACS body should determine whether there are needs and opportunities for mass communication to the public that should be met by allocation or re-direction of Society resources.

The sub-unit mentioned in N4(c) is urgently needed. Whether it be a subcommittee of the Society Committee on Education or a staffed Office within the Education Division, or both, is less important than the creation of the focus.

Recommendations on ALL LEVELS OF EDUCATION

A1 Improving the Qualifications of Today's Teachers

A2 Information Technology and Science Education

A3 Research in Science Education

Photo: Phyllis Marcuccio

One of the views held by members of this Task Force is that good teachers know something about the teaching arts AND about what they teach.

A1: IMPROVING THE QUALIFICATIONS OF TODAY'S TEACHERS

Recommendation: Vigorous and large expansion of National Science Foundation and other Federal programs to upgrade the quality of science instruction through direct service to teachers.

This report of the recommendations of the Task Force is, we hope, colored strongly by our concerns for quality—in particular for the quality of the educational experiences that students have. At some levels of education we know exactly how to pursue that quality, primarily because there is agreement on what it is. At other levels of education it is more difficult to address the issue because there are differing views of it. Some measure quality by how the students feel about what they have learned; some by what the students have learned; some by how the students feel about themselves while learning or after having learned. Since the learning for which we have a care is being done by flesh-and-blood human beings, not by intelligent automata, all of these dimensions and others as well are important.

It is important also that we maintain awareness that there is an ever-changing mix (varying with time, discipline, and individuals) of what is taught and what is learned, of what *is* teaching and what *is* learning. However we learn, it is important that the quality of the teaching be as high as possible.

One of the views held by the members of this Task Force is that good teachers know something about the teaching arts AND about what they teach. Since teaching and learning have powerful behavioral aspects, it is easy to feel accomplishment and satisfaction when one masters the arts, techniques, and some of the science of teaching and learning. But, just as an engine produces no work unless fueled, so the arts of education produce no learning unless fueled with knowledge. At too many levels, in too many places, about too many subjects, those who teach do not have sufficient or new enough knowledge of subject matter to assist sound learning.

We do not attempt to fix blame for this state of affairs. We simply assert that present teachers must be helped to improve the base of knowledge upon which they stand to teach. Further, we assert that although some weakness of the present foundations of teaching may arise from imperfect art, much of it arises from outdated or insufficient content.

During the 1960s and until rather recently the United States Government supported a number of programs designed to assist high school and college teachers of mathematics and the sciences to update and extend the disciplinary knowledge on which their teaching was based. There were summer institutes for both high school and college teachers, science faculty fellowships, and several programs of grants for conferences and short courses. There were consultant and visiting scientist programs, instructional scientific equipment grants, college science improvement programs, grants for summer research for undergraduates, etc. These programs started at the teacher-discipline interface and spread to work on curricula, provision of instrumentation, fostering faculty and student research activities, and a variety of other ways of initiating and maintaining the momentum of knowledge and skills improvement by individual teachers.

Funding for these programs eventually all but disappeared. There were concerns about their effectiveness, particularly their cost effectiveness. Some of the curriculum projects ran onto shoals of various kinds. It was difficult to demonstrate positive results of a cluster of programs whose aggregate costs were several hundreds of millions of dollars. Retrospection has given us a different view: If nothing else, the teacher development programs of the National Science Foundation arrested and for a time reversed the nationwide decline in the quality of science instruction that began before them and continues after; in education as in athletics, continuing capability depends on continued coaching and training—one has to run in order to stand still; and, those programs were among the most effective educational coaching and training efforts ever devised or implemented.

We think it important that there be a continuing national effort to sustain teacher vitality and to motivate the changes in chemistry education at all levels that are necessary in response to the continuous development and change in the discipline. But, the times now demand much more than service to just this important objective.

In some later recommendations we will argue for increased emphasis on science in the primary and elementary grades, both to build in a constructive way upon the natural curiosity of children and to assure that from the earliest years a foundation is slowly and carefully built that will help assure that those choices and decisions related to the facts and methods of science that every citizen is called upon to make or support are wise ones. In other recommendations we will stress the need for more and better student contact with science in secondary schools and in higher education.

If our recommendations for high school and

collegiate curriculum content are received favorably and implemented widely, a larger fraction of new teachers should have the knowledge and skills they need to help students meet and learn science at every level of education. In the meantime, today's teachers need help—and lots of it—if several more generations of students are not to be under-educated (or, worse, dis- or mis-educated) in science. There are many ways to help today's teachers: workshops, conferences, and other in-service activities can reach many in a short time; summer or semester-long institutes can provide new background and updated experience for those requiring more thorough work; materials development and curriculum assistance are important too.

A1. The Chemistry Education Task Force recommends a vigorous and large expansion of National Science Foundation and other Federal programs to upgrade the quality of science instruction through direct service to teachers. Such programs should include not only college and high school faculty members (who were well served by earlier programs of the Foundation) but also elementary school teachers and those specialists in science education at all levels who will bear responsibility in improving the science literacy of the student and general populations. We recommend also that state and local governments match the federal contribution by facilitating and supporting teacher participation in such programs and, in due course, by developing their own systems for assuring teacher improvement and refreshment.

The National Science Board Commission on Precollege Education in Mathematics, Science and Technology has proposed a program of summer and in-service institutes for teacher improvement that would expend $3.49 billion over a five year period. It was proposed that Federal support be half the total, the other half being provided by the states on a matching basis.

The recent transfers of some costly Federal programs to state funding make it unlikely that the states will accept this particular education obligation on the scale that is necessary, even if the effort could be limited to five years. We believe that a program of this kind is a national need and therefore should be a Federal responsibility. Further, the program should be a permanent one, addressing a succession of priorities as changing circumstances warrant.

There are neither the faculties nor the facilities to achieve the objectives of the Commission's proposed program in just five years. A permanent cluster of efforts could be phased-in over a period of 4-6 years, however. Federal funding should be of the order of $200-250 million each year. The states' "match" of these funds will be indirect—higher teacher salaries, support of facilities improvement, provision of more adequate equipment and supplies, etc. Such things might be required of the states, rather than the shared support of direct costs envisioned by the Commission.

A2: INFORMATION TECHNOLOGY AND SCIENCE EDUCATION

Recommendation: Expansion of Federal support of research and development in the use of computers and other information technologies in science education.

Modern information technology—computers, video recording devices, inexpensive electro-optical means of storing and transmitting information, etc.—is creating a wide-reaching revolution in the conduct and even the nature of human affairs. Work, recreation, and education are all being affected profoundly.

For example, the computer is changing quickly and drastically the ways in which commerce and industry are done and the nature of many jobs. It has enhanced greatly the effectiveness of scientists and increased the scope of scientific investigation. The new world created by the computer makes new demands on science education and, fortunately, affords the means to meet these and other educational demands. The whole science curriculum, from elementary school onward, must be changed to prepare students to use computers at work and at home as well as in the classroom and laboratory.

The range of computer applications to science education is enormous: simulations of the behav-

ior of chemical systems; mammoth database capacity; networking of individuals, libraries, and databases; diagnosis of the individual student's current knowledge, mental models, and problem-solving strategies, permitting teacher-tailoring of appropriate learning activities; tireless tutoring; etc.

The changes in school programs that can be made because of these applications cannot be easily or lightly undertaken. All of them, to some extent, put the student and teacher at the mercy of the programmer: simulations assume that the programmer knows what is going to happen; diagnosis is based on the programmer's knowledge of syndromes and judgments concerning their elements. Schools must have guidance based on research and development if they are to be confident of the educational effectiveness of various innovations now possible and if the advanced possibilities that go well beyond present practice are to be explored carefully. Some of the necessary research and development will be carried out in the private sector. But, since private and public purposes to not always coincide, there is need for the United States Government to provide support here, as it does in other areas important to the national interest.

A2. The United States Government should continue and expand its role as a major supporter of research and development in the use of computers and other information technologies in science education, including the establishment of a research and development center to explore the potential of information technology in science education.

a. At present, the National Science Foundation and the National Institute of Education are the main Federal vehicles for provision of support for research in science education. It is likely that the Department of Defense and other Federal agencies, however, are sponsoring research and development work that have substantial application to education. All such agencies should increase the number and expand the support of joint or cooperative research projects that bring together physical and life scientists, teachers, computer scientists, and cognitive scientists to study and develop educational applications of information technology. Because of the number of different disciplines involved in such activity, we propose that the Government establish a demonstration research and development center to explore the potential of information technology in science education for all students.

A3: RESEARCH IN SCIENCE EDUCATION

Recommendation: Expansion of Federal support of research in science education.

The increased emphasis on providing substantial science education to *all* students brings forward questions about the proper objectives of education in science for the general student who will not seek a career in science, how well these objectives have been achieved in the past, and how such achievement can be improved in the future.

Two major objectives of science education are the growth of understanding of basic scientific principles, and the development of the ability to use these principles in reasoning about scientific matters and in solving problems that arise at work and in daily life. Content and subject matter are of critical importance to such growth and development and it is makeshift to rely instead on the short cuts which simulation and algorithmic learning seem to afford.

Research in cognitive science has entered a new and fruitful phase, yielding knowledge that can improve the learning of science by both the general student and the student interested in a science-related career. Cognitive scientists, in collaboration with scientists and teachers in several disciplines, have shown, for example, that students enter upon science instruction with their own mental models of the phenomena that are studied. These models, based on previous observation and experience, are often erroneous, and, like myths, are remarkably resistant to modification, and often remain dominant when science instruction has been completed.

Research on problem solving has shown that novices and more expert persons use quite different approaches: an expert first analyzes the problem in terms of the principles involved, then turns to mathematics to complete the solution; the novice typically seeks immediately a formula connecting the data provided, and is often at a loss if none can be found.

The scientists and teachers pursuing this research believe that a central objective of science education should be to help students develop correct mental models of phenomena (this requires specific attention to modifying the tenacious erroneous models the students bring with them) and to turn to these models rather than to rote formulas when confronted with a problem to be solved.

These and other conclusions that continue to emerge from new research in science education

suggest strongly that substantial modifications are required in existing curricula, teaching practices, and teacher education programs. It is in the national interest that these changes be made and that further research along these promising new directions be supported. As in other areas of national importance, the principal source of research support in science education must be the United States Government.

A3. The United States Government should continue and expand its role as the principal supporter of research in science education, especially through efforts that increase the interactions between and among scientists, science educators, and cognitive scientists.

a. At present, the National Science Foundation and the National Institute of Education are the main Federal vehicles for provision of support for research in science education. These two agencies should increase the number and expand the support of joint or cooperative research projects which bring together teachers, scientists and mathematicians concerned with teaching in their disciplines, and cognitive scientists. Such projects have proved very fruitful in increasing our understanding of both the learning and teaching of science and in suggesting ways to improve them.

b. The Education Division of the American Chemical Society, the corresponding units of other disciplinary associations, and the proposed National Council (N1 and N3) should encourage both the expansion of Federal support of science education research (particularly that involving cognitive science) and the careful application of the results of such research to curricula, in the classroom, and in the education of teachers.

Recommendations on ELEMENTARY SCHOOL SCIENCE

E1 Scientific Societies Effort in Aid of Elementary School Science
E2 Reading, 'Riting, 'Rithmetic, and Rscience
E3 Guidelines for School Science Curricula
E4 Elementary School Teachers of Science
E5 Federal Regional Science Centers
E6 ACS Activities in Pre-High School Chemistry Education

Photo: Charles Frizzell Photography

First and foremost, introductory science should be based on the observation of phenomena and discussions of possible causes.

E1: SCIENTIFIC SOCIETIES EFFORT IN AID OF ELEMENTARY SCHOOL SCIENCE

Recommendation: Coordinated effort by scientific and engineering societies to address the major problems of science education in the elementary schools.

> "The principal goal of education is to create men and women who are capable of doing new things, not simply of repeating what other generations have done . . . who are discoverers. We need pupils who are active, who learn early to find out for themselves, partly by their own spontaneous activity and partly through the materials we set up for them." [Jean Piaget (1896–1981), educational psychologist]

Convincing research suggests that a great many young people lose their early curiosity about natural phenomena and develop negative attitudes about science before they reach high school. Yet, some teachers *do* generate and maintain enthusiasm for science in their students; some schools and school systems produce more science-interested students than others; and many high school graduates are science-literate and have demonstrably acquired that literacy over years of schooling. A suitable curriculum, attention to the individual needs of learners, and teachers who themselves have developed and sustained some enthusiasm for science, can produce students who, at every stage of their progress through the schools, have appropriate knowledge of science, have continuing opportunities to develop an interest in science as a career area, and are becoming sufficiently familiar with science to use it as background for their adult lives.

That the state just described is not universal may arise (ultimately) from unfortunate attitudes such as: lack of parental concern and support for learning, lack of student motivation, and widespread undervaluing of intellectual growth and achievement. These factors and others have created three major barriers to the improvement of elementary school science instruction and the bettering of the attitudes of children toward science:

1. The barrier of insufficient time—20 minutes or so of each school day (about the national average) is not enough;
2. The barrier of presently inadequate curriculum—in spite of a national effort at curriculum improvement some years ago;
3. The barrier of teachers ill-prepared to teach science and encourage students in science.

Later in this section, the Task Force will comment on each of these areas in more detail.

Over the past twenty years, the National Science Foundation has funded a number of science curriculum projects for elementary schools, including: *Science, A Process Approach: Science Curriculum Improvement Study:* and *Elementary Science Study.* Evidence of the extent to which the products of any of these NSF-supported projects have been or are being used in elementary schools varies depending on the report and level of analysis; however, these new curricula in aggregate have never reached as many as a third of the elementary school population at any time, and their use has slowly waned as follow-up and refreshment funding has disappeared.

Science is an incidental topic in most elementary school curricula, and it is no surprise that school administrators and teacher certification bodies have paid little attention to the need to qualify teachers to communicate science in an accurate and effective manner. The same status is among the factors that have produced the present under-emphasis on this subject area which looms so large in the life of the nation.

Making a substantial improvement in the quality of elementary school science education will be a formidable task, but it must be done. New resources and new energies must be brought to bear on the task. It is not enough to start with alarm and finish by "giving everyone the same little bit to bring about the same little change." This Task Force believes that the nation's associations of qualified technical professionals have a responsibility to provide both guidance and participatory leadership to a national effort to raise the quality and quantity of the science instruction received by our children.

E1. A coordinated effort by the American Chemical Society and other national scientific and engineering societies should be mounted to address three major problems of science education in the elementary schools: the insufficient time devoted to it; the less-than-desirable quality of the curriculum and educational materials; and the lower-than-necessary qualifications and preparation of the teachers charged with direct responsibility for it.

a. This effort could be led by the American Association for the Advancement of Science, which has long given special attention to science in the schools. Educational societies, such as the National Science Teachers Association, could play important roles also.

b. The centrality of chemistry to its sister sci-

ences and the importance of chemical phenomena to every aspect of daily life require that there be a chemistry component to science instruction at all grade levels; chemistry is too important to be left until there is time for a "unit" or "mini-course" in the middle or junior high school curriculum, or for a "course" in high school. Leadership in this aspect of the national task is appropriately that of the American Chemical Society through instruments such as the (governance) Society Committee on Education, (staff) Education Division, and (membership) Division of Chemical Education.

c. We recommend that state and local teacher certification be dependent on regular participation in subject matter-oriented educational activities such as workshops and institutes, as well as on similar efforts directed toward improvement of skills and methods.

E2: READING, 'RITING, 'RITHMETIC, AND RSCIENCE

Recommendation: An immediate national effort by scientific and engineering societies to add science to the present basic triad of school subjects.

The remarkable success of "American" scientists in achieving the levels of insight, ingenuity, and indefatigability that lead to Nobel Prizes has been ascribed to everything from the flight of scientists from Nazi Germany to the superiority of the entrepreneurial climate fostered by the way science is organized and supported in the United States. But, few indeed are those who have laid the laurel wreath at the foot of the American school system.

The purpose of science education in the elementary schools ought not to be to assure future Nobelists of appropriate initial preparation, but it should not cut off that possibility. The purpose ought not to be to initiate the intense pre-career contact with science that might benefit students who are as excited about natural phenomena as some youths are about basketball, but neither should their excitement go unanswered or even unstimulated. The purpose ought to be to give every student an understanding of what science is and is about that will permit, not inhibit, encourage, not discourage, and provide a foundation for that entirety of school-taught science that is foundational to effective citizenship.

There is too little science of any kind taught in elementary school. Since little science is taught, few students get enough exposure that responds to their interest and curiosity if they have it, or stimulates it if they do not. The results are poor awareness of science and poor discrimination with regard to science-based matters arising in adult life—poor preparation for meeting the demands of life in an increasingly technologically-oriented environment—and many fewer students interested in science-related careers than is in the national interest.

Comparisons with the patterns in European countries reveal some of our shortcomings in elementary level science education. *They* devote 25–30 percent of class time to instruction in science and mathematics, in a school year averaging 240 days of 7–8 hours contact; *we* spend 20–25 percent of class time in such instruction, in a school year averaging 180 days of about 5 hours contact. Japan perceives that it is in the national interest to provide advanced education in science and engineering to two to three times as many students as are necessary to meet immediate employment demands, believing, apparently, that the worker in a nonscience profession who has a science background makes a positive contribution to the national welfare, including the gross national product. The patterns of American education, by contrast, are increasingly driven by short-term vocational forces.

E2. The American Chemical Society and other national science and engineering societies should begin an immediate national effort to add science to the present basic triad of school subjects—reading, writing, and basic mathematics.

a. It would help to increase to 25–30 percent the proportion of the school day that is devoted to instruction in science and mathematics. Substantial improvement would also be attained if the percentage were maintained while the school day were lengthened. Mathematics already has 45 minutes of the elementary school day; it is the time devoted to science instruction that must be increased.

b. One sure way to assist the increase of attention to science instruction in the elementary school curriculum is to expect science achievement on the part of all students. Therefore, the testing of science learning must be made a major part of any program of assessment of student progress. Achievement testing is, however, but one of the mechanisms which must be employed to assure the *quality* and *content* of instruction in science (and in every other area); the nation does not need more time devoted to pap.

Finally, we observe that students can be required to *read and write about science*; no sacrifice of learning of communication skills is necessary in order to increase the efforts in science and mathematics.

E3: GUIDELINES FOR SCHOOL SCIENCE CURRICULA

Recommendation: Development of model science programs for each grade level K-8

A chemist thinks immediately of certain concepts and facts that ought to be taught to elementary school students; a physicist, biologist, astronomer, or geologist might draw up a rather different list. There is certainly no single best way to expose school children to science, but there are certain features of that exposure on which most scientists would agree. First and foremost, introductory science should be based on the observation of phenomena and discussion of possible causes. Second, students should be given the opportunity to carry out simple experiments (and watching the growth of a planted seed is an *experiment* if a second seed is planted or grown under slightly different conditions).

It seems safe to say that all physical scientists would agree that one important aspect of school introductory science is the observation of quantitative relationships (larger/smaller, less/more, faster/slower), and that another is the observation of changes in properties (color, physical form, energy content, solubility). It is doubtful that elementary school students should be prepared specifically for the wave mechanics presently (and inappropriately) introduced in the high school, but the particulate nature of matter is something that they should be led to understand at an early stage.

In brief, there are many descriptive and conceptual matters that can and should be introduced to all students through well-designed and well-considered elementary school science curriculum elements.

E3. A model science program for each grade level K-8 should be developed under the auspices of the National Council (N3), with each major science society assuming responsibility for assisting the creation of curriculum guideline components in its disciplinary area. It is critical that science instruction in the elementary grades be based on observation of phenomena, and that it contain descriptive, quantitative, and conceptual elements.

a. As part of its participation in the proposed national effort (E1), and consistent with the objectives of the present recommendation, the appropriate units of the American Chemical Society should sponsor the development of chemistry modules for each grade level with special emphases on ease and safety of use and on low cost.

b. This Task Force recommends that the American Chemical Society and its sister science and engineering associations join to inform the public of the need for observation-based elementary science education so that the local and state financing bodies will be supported in their quest for the additional funds that may be required to equip classrooms and provide instructional kits for such "hands-on" science in the schools.

E4: ELEMENTARY SCHOOL TEACHERS OF SCIENCE

Recommendation: Development of guidelines for certification of elementary school teachers to teach science.

There is a critical shortage of teachers who are qualified to teach the science that ought to be in the elementary school curriculum. Few teachers who do teach science in elementary schools are well prepared to do so. Neither the fiscal nor psychological rewards of school teaching are adequate or appropriate. Teachers with skills marketable outside education are easily tempted into other and more rewarding careers.

Half of the 45 leading teacher education institutions require 8 semester hours or less of college-level science in their elementary education curricula. In one large school district in a relatively wealthy state in the Southeast, 12 percent of the teachers of elementary school science had taken no college-level science at all before starting master's level degree work in education, 20 percent had taken no course in the methods of science or the methods of teaching science, and 65 percent had never attended an in-service seminar or workshop on science teaching. In many states, elementary and middle school teachers can be certificated with as little as one college-level science course, and in most states there is no certification

requirement of coursework in methods of teaching science. Among teachers, the level of expression of self-confidence to teach the material in the curriculum is a fifth to a third as high with respect to science instruction as it is with respect to instruction in reading, social studies, or (even) mathematics.

E4. This Task Force recommends that the National Council (N3), with respect to the development of model K-8 science programs under its auspices, set forth guidelines for certification of elementary school teachers to teach science; and, we recommend that those guidelines require of such teachers before certification the successful completion of at least 3 one-year courses in the sciences, a balanced selection being required among courses in the biological, earth, and physical sciences.

a. Further, we recommend that the National Council and its component scientific and engineering societies mount programs of public information in support of the changes in conditions of employment of elementary school teachers which, in fairness, should accompany more stringent requirements for their professional certification—changes such as: compensation competitive with alternative careers; scholarship, tax-preference, and other financial inducements to enter and remain in teaching; salary schedule advancement and tuition assistance for subject matter continuing education in addition to that derived from methods education and longevity; and released time for the special preparations that are necessary for the safe and effective teaching of science to children.

b. We recommend that elementary school teachers with a specialty in science, perhaps as members of a teaching team, be used to provide sound instruction during the period in which individual classroom teacher preparation for science instruction is being brought up to adequate levels.

c. Finally, we urge the participation of present elementary school teachers in programs designed to improve their knowledge of science and science teaching (A1).

E5: FEDERAL REGIONAL SCIENCE CENTERS

Recommendation: Establishment of Federally supported Regional Science Centers as focal points for improvement of precollege science education.

Curriculum guidelines and increased teacher certification requirements will be regarded as *hurdles* by some who, otherwise, agree that steps must be taken to improve the quantity and quality of elementary school science teaching. Further, there is no doubt that such components of a general remedy have a long-range but slow-acting aspect. *Help* is needed in addition for those who presently teach in elementary schools, most of whom will continue to do so; help that, though continuing, is shorter-range and faster-acting.

This Task Force believes that two kinds of help would be especially useful: (1) assistance to teachers in the form of new curricular and instructional materials; (2) assistance to teachers in the form of educational activities and experiences for them designed to strengthen their knowledge and understanding of science and of recent research findings on the effective teaching of science, and to strengthen their self-confidence to present science and supervise student activity in the classroom.

To these ends:

E5. As many as ten Regional Science Centers should be established and supported by the United States Government to provide focal points for the improvement of precollege science education through teacher service programs, curriculum and materials development projects, the provision of expert consultation, etc. The small permanent staff of each center should be strongly discipline-oriented, and each center should serve several disciplines selected in view of regional needs.

a. It would be appropriate that the National Council (N3) (a) direct the selection of the host institution for each such center by formulating the selection criteria and in other ways, and (b) serve as an independent supervisory body for the whole program. It is very desirable that the base funding for the Science Centers program be provided by the National Science Foundation since, in this and other ways, it

is important that these centers have strong science discipline character.

b. We believe that there should be contributory financial support to the Regional Centers from the states. The financial role of school districts and institutions of higher education will be manifest in their partial support of teachers and faculty members assigned to the Centers for limited periods. The contributions of industry to this program in the national interest can be the most varied of all, ranging from direct financial contributions, through the donation of other kinds of material resources, to the temporary loan of skilled and interested professionals.

The program of each regional center should be sensitive to the general and specific needs of the member states as well as to defined national objectives in science education K-12. The ten or so centers should be only lightly tied together, but there should be free flow between them of expertise and developed products. A broad spectrum of science disciplines should be represented at each center, such diversity being necessary to meet the needs of both elementary and secondary schools. Cognitive science and information technology specialists must be part of the staffing of every center. Center programs will have important currency and vitality if both academic and industrial scientists are included in the rotating staff.

The centers should be located optimally with respect to significant factors such as: convenience of access to teachers for short-term assignments; strong academic support by a host institution (which should have well-established and high quality programs in all of the basic sciences); availability of laboratory, other educational, and visitor residence facilities (though some dedicated to the centers would be expected to be constructed under the program as it matured).

Teachers will not become involved in the programs of the Regional Science Centers if they are disadvantaged financially by such participation. Even highly compensated health professionals pursue required continuing education only when suitable incentives are provided; greater self-sacrifice should not be expected of the nation's poorly compensated and much maligned teachers. Federal support, possibly tied to state and school district support, should be made available for summer salaries of teachers participating in institutes or workshops, for sabbatical leave salaries of teachers serving as rotating staff members, for university and college faculty directing and carrying out staff functions, etc. We recommend that state and local teacher certification be dependent on regular participation in educational activities such as the workshops and institutes which would be programmed by regional centers, and other subject matter-oriented education.

Our view of the importance of new curricular and instructional materials is parallel to that of The National Commission on Excellence in Education:

> "Textbooks and other tools of learning and teaching should be upgraded and updated to assure more rigorous content. We call upon university scientists, scholars, and members of professional societies, in collaboration with master teachers, to help in this task, as they did in the post-Sputnik era. They should assist willing publishers in developing the products or publish their own alternatives where there are persistent inadequacies."

Although teacher participation in Center programs should over time, improve school science instruction, the creation and dissemination of curriculum and instructional materials developed or selected through Center activities would provide immediate assistance to a large number of school districts. Federal budgeting for the regional centers should include substantial sums for both development and dissemination of materials.

It should be noted that several regional science centers were established under a former NSF program. Their experience should permit avoidance of many pitfalls in the development of the centers proposed here.

E6: ACS ACTIVITIES IN PRE-HIGH SCHOOL CHEMISTRY EDUCATION

Recommendation: Expansion of ACS activities in the area of pre-high school chemistry education.

The American Chemical Society recently has established an Office of High School Chemistry in its (staff) Education Division to implement a wide variety of programs in support of high school chemistry teaching, including that intended for the general (nonscience oriented) student. In this and preceding sections of this Report, we have identified and proposed a number of new responsibilities that should be undertaken by the Society. Other responsibilities for the Society are implied by the recommendations of the 1982 ACS Invitational Education Workshop on *Chemistry in*

the Kindergarten-through-Ninth-Grade Curricula, and by the recommendations in other recent national reports, especially that of The National Commission on Excellence in Education. It is, therefore, appropriate and timely that an ACS staff function be created to serve pre-high school chemistry education.

E6. The American Chemical Society should expand its activities in the area of pre-high school chemistry education to implement the recommendations of recent ACS studies, those from other national reports, and other elements of ACS science education policy as they apply to the pre-high school years.

a. Initially, this assignment might be given to the present Office of High School Chemistry, making it, in effect, an office with responsibilities covering the whole of precollege education. Experience should determine the desirability of and need for a separate office for the pre-high school activities of the Society.

b. Among the specific responsibilities of the expanded staff function should be the stimulation of increased interaction between elementary school teachers with a specialty in science and both academic and industrial scientists. It should also sponsor the preparation of teaching modules for use at various grade levels K-9, consistent with the curriculum recommendations of the National Council and presenting chemistry from a sound and balanced perspective appropriate to its centrality among the sciences.

Recommendations on HIGH SCHOOL CHEMISTRY AND SCIENCE

H1 A Five-Year Plan to Improve Chemistry Education in the High Schools
H2 Raise Teacher Certification Standards: Improve Qualifications
H3 Science Requirement for High School Graduation
H4 High School Chemistry Courses
H5 The Laboratory Component of High School Chemistry

Photo: National Science Teachers Association

Colleges and universities should offer at convenient times and in accessible locations those formal courses that would permit numbers of individuals in their service areas to complete certification requirements, pursue advanced degrees, and in other ways increase their potential as knowledgable and qualified high school teachers.

H1: A FIVE-YEAR PLAN TO IMPROVE CHEMISTRY EDUCATION IN THE HIGH SCHOOLS

Recommendation: Creation of an ACS 5-year plan to improve chemistry education nationwide in the high schools.

No level of science education has attracted more numerous expressions of concern and more varied suggestions for remedy during the work of this Task Force than the high school level. High school is where the science awareness and science literacy of students can be powerfully advanced by the simultaneous application to subject matter and issue-oriented material of all the learning skills developed to that time. High school is where serious interests develop, the general areas in which careers might be pursued are explored, and where tentative choices are made. High school is where those with a particular orientation can be exposed to work supporting that orientation—to study that demands of them some rigor, intensity, and sophistication of effort, and rewards them with achievement and senses of accomplishment and identification.

At present, science education in the high schools taken as a group reflects neither the personal significance nor the national importance of the subject.

The shortage of properly qualified teachers is well documented; many now in service appear to have had training that is at best marginal for the demands of current science instruction; few are compensated at levels appropriate to the importance of their efforts or competitive with other and increasingly attractive opportunities.

There are only inadequate resources and programs available for the refreshment and upgrading of the background of those effective and interested science teachers who elect to remain in the high schools; indeed, the national effort in support of such programs has waned just as the national dependence on its results has waxed.

There are excellent programs in chemistry that work for the most strongly motivated students, including many who will elect a career in science, but these fine programs appear to be less effective for those with nascent potential in science. The less challenging courses that are generally available fail to motivate high ability students sufficiently to make even a tentative choice of one of the chemical sciences as a career. Further, students without career interests in science do not, in general, receive instruction in chemistry adequate for discriminating and intelligent citizenship.

Chemistry and other laboratory sciences are often taught as if they were done and over with, instead of being presented as open-ended and experimental fields (computer simulation is especially pernicious because it *does* implant the notion that somebody already knows all the answers); opportunities for students to study chemical change through their own efforts in properly equipped instructional laboratories are decreasing.

H1. The American Chemical Society's Division of Chemical Education and the Society Committee on Education, in consultation with appropriate other bodies and individuals, especially high school chemistry teachers, should create a 5-year plan for using available and expected resources to improve chemistry education nationwide in the high schools. This plan should provide a priority listing of goals, programs, and activities for pursuit during five years by the education components of the Society, and should relate to likely and desirable programs supported by the United States Government, by state governments, and by private industry.

The most critical areas in need of attention are the quality of the teacher, the quality of the content of chemistry courses, and the quality of the experience afforded to all students.

a. We recommend also, that the American Chemical Society's Committee on Education, in concert with selected representatives of the Society's governance and operating structure, develop machinery that will enable chemists to influence appropriately and significantly the planning, development, and implementation of the forthcoming changes in science education, especially at the high school level, that will follow upon the recommendations of The National Commission on Excellence in Education (which reported in April 1983) and The National Science Board Commission on Precollege Education in Mathematics, Science, and Technology (which reported in September 1983).

b. While it is unlikely that the Society could, at this time, undertake high school chemistry program approval, it should do more to add force to its recommendations for teacher preparation and continuing education. Education committees of ACS local sections might be willing to assist high schools in their areas and work for public support of better chemistry education in their communities. The most powerful force for educational improvement is an informed and aroused constituency.

H2: RAISE TEACHER CERTIFICATION STANDARDS: IMPROVE QUALIFICATIONS

Recommendation: A national effort to raise teacher certification standards in science and mathematics and to secure adherence to such standards.

The majority of secondary school teachers certified to teach chemistry are competent to teach basic chemical principles and to present the existing curriculum effectively and with understanding. But even such teachers need ways of maintaining and advancing their professional skills beyond those that are conveniently available at this time. Unfortunately, the vast majority of secondary school students are not being taught chemistry by certificated teachers of chemistry—they are being taught by persons who have minimal background in the subject and little if any qualification to maintain and advance their working familiarity with it, however acquired. As there is a critical mass in explosions, so is there a critical amount of background necessary before teachers at any level can be self-sustaining in updating their skills in and refreshing their knowledge of any subject. Most persons who teach chemistry in the secondary schools today do not have that critical amount of background in chemistry.

According to recent surveys and samplings: over half of newly appointed science teachers have qualifications less than the often low existing state standards; among teachers whose class assignments are ar least half in science courses, 32 percent majored in a science; and, the number of students graduating each year with majors in science *instruction* (which is short of the optimal preparation for high school science teaching) is less than the need in 40 of the 50 states.

It is clear that standards for certification of teachers to teach science must be increased, that present teachers must be assisted to maintain and improve their science-related professional skills, and that present and future teachers must be afforded the status and compensation which are among the most powerful incentives to keeping good teachers in good schools instead of losing them to satisfying employment outside education. The present mismatch between necessary and actual qualifications and numbers of high school teachers of science, especially chemistry, must no longer be tolerated.

H2: The National Council (N1), the American Chemical Society, other science societies, and the appropriate agencies of the United States Government should work more closely and more forcefully with state education agencies: (a) to raise teacher certification standards in science and mathematics; and (b) to set limits on administrative use of emergency or temporary certification (which tends to continue indefinitely) of persons underqualified to offer sound science instruction. To the former end, the American Chemical Society should review and update its 1977 "Guidelines and Recommendations for the Preparation and Continuing Education of Secondary School Teachers of Chemistry"; to the latter, the Society should increase its own efforts to bring into high school teaching professional scientists who are qualified in science education.

No matter what improvements in the high school science curriculum are devised and implemented to increase the science awareness and literacy of students, or to furnish a basis for their serious consideration of science-related careers, it is the high school science teacher who will present that curriculum and whose qualifications will, in large part, determine its success. In earlier sections of this report, the Task Force urged immediate action of two fronts to increase the opportunities for updating and upgrading the science-related professional competencies of high school teachers of science, including chemistry: in Section A1, the whole panoply of programs of teacher improvement funded by the National Science Foundation; in Section E5, Regional Science Centers, which have a role to play in the improvement of secondary school science instruction at least as significant as their role in elementary school science education. An even greater variety of opportunities needs to be made available, because of the diversity of the personal and professional situations of individual high school teachers.

a. Sound preparation for teaching chemistry in high school is similar to the content of the undergraduate liberal arts major in chemistry (30–35 semester hours of chemistry, 10–15 of physics, 10–15 of mathematics, and substantial work in English and a foreign language) plus professional work in preparation for teaching in general and for teaching laboratory-centered science in particular (12–18 hours).

b. Workshops should be offered for college or other acceptable credit that would allow high school chemistry teachers, through evening, Saturday, or summer attendance, to become more knowledgeable in the field of chemistry. Updating and strengthening of information on basic concepts, applications of chemistry, and chemical facts are especially useful and needed.

c. Colleges and universities should offer at convenient times and in accessible locations those formal courses that would permit numbers of individuals in their service areas to complete certification requirements, pursue advanced degrees, and in other ways increase their potential as knowledgeable and qualified high school chemistry teachers. Similar programs, especially in the area of professional education, should be made available to professional scientists who wish, upon retirement or at other times, to assist the national effort to improve high school science instruction by becoming qualified high school teachers themselves, full- or part-time. [An example of such a program is that in St. Louis sponsored jointly by the Monsanto Company and Washington University.]

d. We recommend that the National Council and its component scientific and engineering societies mount programs of public information in support of the changes in conditions of employment of high school teachers necessary to attract qualified persons to such teaching and to retain them there. These changes include: compensation competitive with alternative careers; scholarship, tax-preference, and other financial inducements to enter and remain in teaching; salary schedule advancement and tuition assistance for subject matter continuing education in addition to that derived from methods education and longevity; released time for the special preparations that are necessary for the safe and effective teaching of science at the high school level; and the allocations of both personal assistance and material resources to the laboratory component of instruction required for its effectiveness and safety.

e. Because optimally-prepared high school chemistry teachers who keep abreast of their science are attractive to other employers, it would be in the national interest for such employers to work with school districts and individual teachers to develop programs that share these scarce persons between academic and private sector employment. Summer positions in industrial laboratories have long been available to qualified high school teachers; we commend such arrangements and urge their substantial increase and expansion. Industry can do much in other ways: by supporting special equipment needs, sponsoring awards for both student and teacher excellence, and by making *its* interested and qualified personnel available to the nation's schools. (It is gratifying that Congress is now considering several pieces of legislation that would support such industry involvement in the improvement of science education.)

f. The overall effectiveness of education in science would be improved significantly by closer interactions between high school and college faculties. The Task Force recommends strongly that individual colleges and universities assume leadership in developing opportunities for such interactions. In the field of chemistry, the local sections (membership) of the American Chemical Society could provide interested and qualified persons to assist these efforts.

H3: SCIENCE REQUIREMENT FOR HIGH SCHOOL GRADUATION

Recommendation: Adoption of a national minimum standard that 3 years of science taught with laboratory and 3 years of mathematics be required for graduation from high school.

For twenty years or more, academic requirements for graduation from high school have been steadily eroded. There are many reasons for this trend, and the forms taken by the erosion are similarly diverse. Science has been an important aspect of the national life for over a century, and its importance continues to increase. It is in the high school that society has its last opportunity to assure that all its future adult citizens have a sound basis in science for citizenship. It is in the high school that students become aware of the existence of the enormous number of career opportunities that depend to some substantial degree on the acquisition of foundational knowledge of disciplinary science. And, it is in high school where students can first be shown, through application of the learning skills already acquired, something of the structure and detail of the great disciplinary areas, science foremost among them.

The address of some of these objectives for all students and all of these objectives for some students requires real contact with at least the three great central sciences—biology, chemistry, and physics. We do not argue for any particular approach to any of them, for "equal time," or for any one sequence. We do argue that all students should be exposed to all three of them and that there should be hands-on laboratory experience in all three of them.

H3. The National Council (N1) supported by the American Chemical Society and other science societies should work closely and forcefully with state school boards and other education agencies toward a national minimum standard that 3 years of mathematics and 3 years of science taught with laboratory be required for graduation from high school, the latter including substantial amounts of biology, chemistry, and physics.

a. This proposed standard is consistent with Recommendation A (curriculum content) of The National Commission on Excellence in Education. We urge immediate effort towards its adoption.

b. Parallel to the need for substantial science in the high school curriculum is that for improved guidance of students by high school counselors as to the career opportunities related to that science instruction. The science societies have an obligation to improve and extend their services to high school counselors through updating of their present information materials, provision for counselor workshops, and other means of establishing and maintaining effective communication between the present and potential workers in science-related occupations.

c. We recommend also that high school guidance counseling be so conducted that students are made aware early that *every* career preparation of lasting value requires a sequence of commitments over the high school years and beyond. High school curricula should be broad and general so that options are not inadvertently foreclosed. This is an especially serious problem in technical areas because the ability of colleges and universities to remedy omissions from the high school years is decreasing rapidly.

H4: HIGH SCHOOL CHEMISTRY COURSES

Recommendation: Study of changes necessary to improve the high school chemistry curriculum.

Earlier we noted that the present high school science curriculum appears to work for the most strongly motivated students, but not for those whose interest in science is nascent or quiescent. Part of the problem seems to lie in the apparent necessity for many high schools to offer just one chemistry course. Especially if some significant exposure to chemistry, including laboratory, is to be required of all students, some accommodation must be made to the fact that a majority may not pursue more advanced study of chemistry.

At least two different types of high school chemistry courses could be developed and offered. One would be a course intended to convey to the nonscience student some of the structure and detail of modern chemistry, with emphases on the chemistry that is involved in the phenomena of everyday life; how chemistry is similar to other sciences, related to them, and differs from them; what national problems and opportunities have a significant chemistry component. The other would be a truly modern course that would give an introduction to chemistry to those students who are likely to make career choices that will require additional formal work in the science; it would cover the same general topics as the course for nonscience students, but would emphasize chemical fact, the ways of establishing chemical fact, the ways of organizing chemical fact, and would introduce the students to the different ways of thinking about chemical knowledge.

Both of these courses require attention from the chemical profession itself, and should not be developed by high school teachers only, college and university teachers only, or even by a combination of just these two groups.

We recognize that our beliefs about chemistry courses may not have the universal serviceability we hope for them. Therefore:

H4. The National Council (N1) should guide a study by the American Chemical Society, with appropriate contributions from societies centered in sister disciplines, of the high school chemistry curriculum and recommend such changes as are found necessary to improve the effectiveness and utility of that curriculum. Resources should be developed to encourage high schools with sufficient enrollment to offer two (or more) different chemistry courses, to meet the needs of different major fractions of their students.

a. We encourage experimentation with ways of incorporating chemistry into the description of phenomena widely throughout the entire school curriculum so that, as students approach upper-level courses, they have sufficient background to make intelligent choices among the different kinds of chemistry courses available to them, and that those choices are not foreclosed.

b. We discourage as strongly as possible developments in high school chemistry courses which make them into descriptive, elementary, or warm-up versions of the first year college chemistry courses. Introductory college chemistry has its own problems and the widespread emulation of its content in high school courses, and, worse, in texts intended for them, is a disservice to many students at both levels. Perhaps the most salutary result of closer interactions between college and high school chemistry faculty members would be spreading agreement on the division of the tasks we share.

c. High school chemistry courses should have the characteristics recommended by The National Commission on Excellence in Education: "The teaching of science in high school should provide graduates with an introduction to: (a) the concepts, laws, and processes of the . . . sciences; (b) the methods of scientific inquiry and reasoning; (c) the application of scientific knowledge to everyday life; and (d) the social and environmental implications of scientific and technological development."

H5: THE LABORATORY COMPONENT OF HIGH SCHOOL CHEMISTRY

Recommendation: Adoption of a guideline that at least 30 percent of class time be devoted to laboratory exercises in the high school chemistry curriculum.

"While reading a textbook of chemistry, I came upon the statement, 'nitric acid acts upon copper' . . . and I determined to see what this meant . . . Having located some nitric acid, . . . I had only to learn what the words 'act upon' meant . . . In the interest of knowledge I was even willing to sacrifice one of the few copper cents then in my possession. I put one of them on the table; opened the bottle marked 'nitric acid'; poured some of the liquid on the copper; and prepared to make an observation. But what was this wonderful thing which I beheld? The cent had already changed, and it was no small change either. A greenish blue liquid formed and fumed over the cent on the table. The air became colored dark red . . . How should I stop this? I tried by picking the cent up and throwing it out the window . . . I learned another fact; nitric acid acts upon fingers. The pain led to another unpremeditated experiment. I drew my fingers across my trousers and discovered nitric acid acts upon trousers . . . That was the most impressive experiment . . . I have ever performed. I tell of it even now with interest. It was a revelation to me. Plainly the only way to learn about such remarkable kinds of action is to see the results, to experiment, to work in a laboratory." [Ira Remsen (1846–1927), educator, chemist]

Chemistry is a laboratory science. But, as teacher qualifications have declined and costs have increased, the amount of time devoted to student laboratory exercises in high school chemistry has decreased steadily. In many schools, demonstrations by the teacher (always an important and effective mode of instruction) are the only opportunities afforded students to observe the phenomena of chemistry. Chemistry is an experimental science. Its great attraction as intellectual experience and training is that even a beginner can carry out experiments that yield observations to be interpreted and explained. With even a little experience, a student can make measurements of chemical phenomena and learn the techniques for converting quantitative data into testable hypotheses.

Recently, computer simulation of laboratory exercises has seemed to afford relief from the costs and logistical problems associated with the maintenance and conduct of student laboratory work, particularly in high schools. The novelty and attractiveness of some computer simulations cannot be doubted, but neither can their inappropriateness as a *substitute* for hands-on student laboratory experience. The computer does have a place in the chemical laboratory: as a data processor, to permit unusual and effective display of the results of student observations, as a tutor in methods and procedures, and as evaluator of learning and understanding; but computer simulation is not a desirable or effective substitute for direct experience with the behavior of chemical systems.

H5. The Task Force recommends that any American Chemical Society guideline for the high school chemistry curriculum provide that at least 30 percent of class time be devoted to student laboratory exercises. The Society's education bodies should study the costs as well as the content of laboratory instruction and recommend ways in which effectiveness can be maintained when resources are limited.

a. It is possible that some of the rapid increase in high school laboratory costs are the result of imitation there of the kinds of exercises done in the first year general chemistry laboratories in colleges and universities. Colleges and universities are under the same kinds of fiscal pressures experienced by school districts; neither should do the work of the other. Academic chemists should join with interested chemists from industry to develop laboratory exercises for both school and college courses that are faithful to the content of modern chemistry without requiring its sophisticated instrumentation.

Surveys which have included students show that they are enthusiastic about laboratory work—in all high school science courses, not just chemistry. It is important that constructive educational use be made of the enthusiasm, especially since this finding is independent of whether the student is self-classified as "science-oriented" or "general."

Recommendations on TWO-YEAR COLLEGE CHEMISTRY AND CHEMICAL TECHNOLOGY

T1 American Chemical Society Guidelines for Chemistry in the Two-Year Colleges

T2 Outreach and Consultation in Aid of Instructional Improvement

T3 American Chemical Society Approval of Chemical Technology Programs

T4 ACS Approval of Other Two-Year College Programs in Chemistry

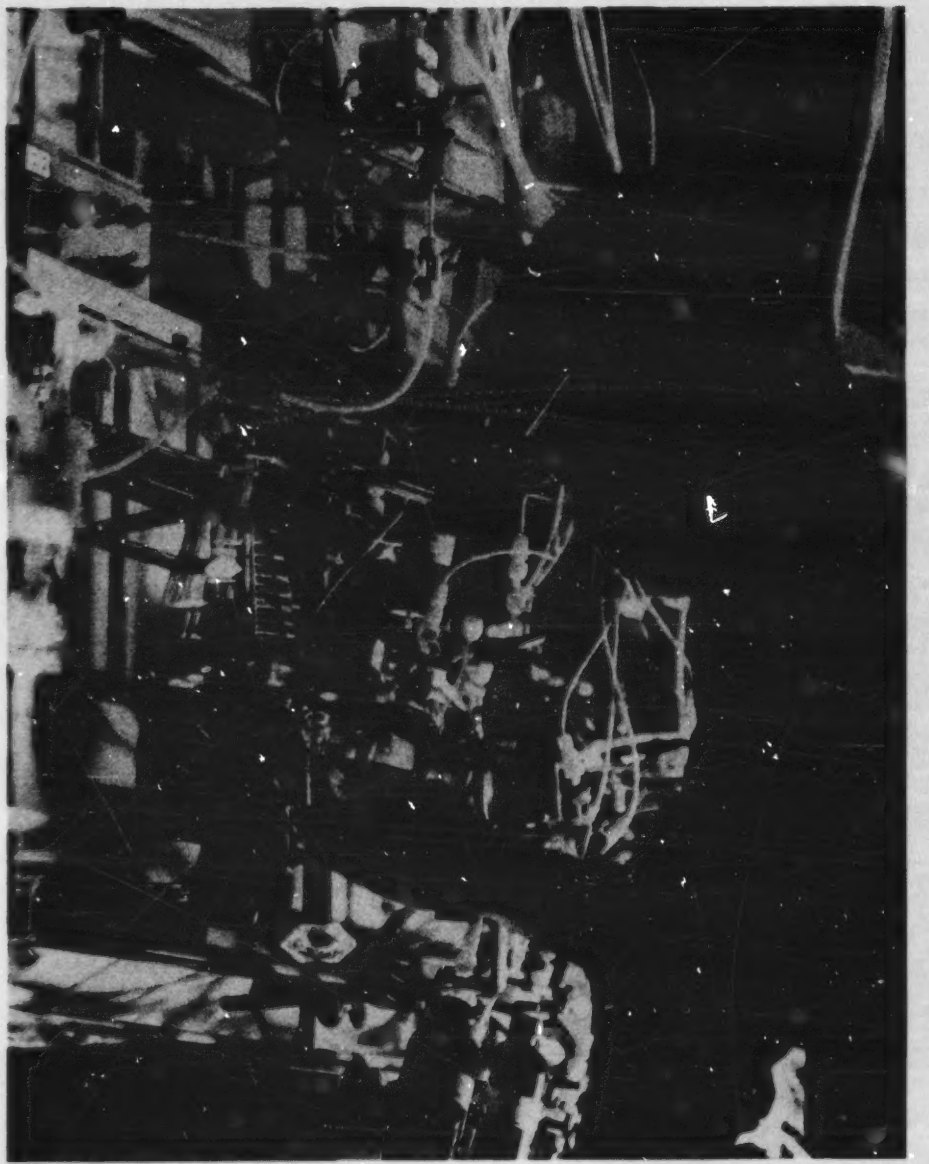

Photo: Monsanto Company

The American two-year college . . . must meet the high standards of those who accept its output . . .

T1: AMERICAN CHEMICAL SOCIETY GUIDELINES FOR CHEMISTRY IN THE TWO-YEAR COLLEGES

Recommendation: Revision of the ACS 1970 "Guidelines for Chemistry in the Two-Year Colleges"

The American two-year college has the most diverse and perhaps the most demanding constituencies of any of the kinds of educational institutions flourishing in the United States today. In every dimension it is complex and broad. It is called upon to prepare students for specific occupations and for transfer to four-year institutions; it must meet the high standards of those who accept its output while repairing the effects of too low standards employed by those who produce its input; it enjoys both multiple financial support and multiple bureaucratic oversight; and, in addition, it must meet the self-defined educational needs of a substantial fraction of the adult population.

The implications of these characteristics for two-year college instruction in chemistry have been examined several times. Notable among such studies were the 1969 *Conference on Science in the Two-Year College* (sponsored by several of the then extant science commissions) and the 1980 review (supported by the National Science Foundation) by the Center for the Study of Community Colleges resulting in the report "*Science Education in Two-Year Colleges: Chemistry.*" However, there is little evidence that their recommendations, which were published widely, were utilized by such colleges or their parent systems to improve or even to maintain the quality of chemistry or other science instruction programs.

The American Chemical Society, after a thorough study, published in 1970 a set of *Guidelines for Chemistry in the Two-Year Colleges*, somewhat analogous to that for undergraduate professional education in chemistry published by the Society's Committee on Professional Training. Because there was no implementation monitoring or compliance review mechanism established, analogous to the Committee's approval program for undergraduate pre-professional curricula, the 1970 Guidelines have not had the beneficial effects expected of them.

Recommendation T1 and others that follow recognize the need to update the 1970 *Guidelines* and, by developing an action plan for their utilization, make them an effective instrument for instructional improvement.

T1. The American Chemical Society Committee on Education should undertake to revise the 1970 "Guidelines for Chemistry in the Two-Year Colleges" to reflect the diversity of chemistry education responsibilities that have become the norm for individual two-year colleges in the past 15 years.

a. This revision should reflect the comprehensive nature of two-year college chemistry programs rather than be limited to the transfer programs for intended chemistry majors. Further, the revision should address two major issues which have special intensity in the two-year colleges: standards for student performance, and adequate funding requirements.

b. If there is to be acceptance and utilization of the revised *Guidelines*, they should be accompanied by suggestions of the appropriate audiences to receive them and effective methods for their implementation at the departmental, institutional, and system levels.

T2: OUTREACH AND CONSULTATION IN AID OF INSTRUCTIONAL IMPROVEMENT

Recommendation: Development by ACS of an outreach and consultation program to assist improvement of chemistry programs in two-year colleges.

Because of their internal diversity and complexity, two-year colleges present difficult management problems. Few of their top administrators have science or engineering backgrounds. "Guidelines," and other forms of "approval" or "accreditation" standards, justifiably can be viewed with suspicion. The American Chemical Society has a long and distinguished record of non-coercive encouragement of and support for the maintenance and improvement of quality chemistry education at the undergraduate level. Since the two-year colleges are an important fraction of the national apparatus for undergraduate education, the Society should take steps to bring to them the same kind of outreach and consultation in aid of instructional improvement that has been available to institutions awarding the baccalaureate degree.

T2. The American Chemical Society should develop an outreach and consultation program that would make the expertise of the Society staff and membership more effectively available to two-year college administrators whose institutions are engaged in substantial efforts to improve the quality of their chemistry programs.

a. In support of such activities, it would be desirable for the National Council and its component discipline-related associations to undertake studies of the special costs needed to maintain science instructional programs of the necessary quality, so that such information is available to administrators and consultants. Further, these studies might well give attention to the development of new approaches to funding these special costs. Local industry, a major employer of the occupationally-educated two-year college graduate, has been a generous supplier of nearly-state-of-the-art equipment to such educational programs. These efforts need to be expanded, and their analogue for academic transfer program instrumentation and equipment needs must be developed.

T3: AMERICAN CHEMICAL SOCIETY APPROVAL OF CHEMICAL TECHNOLOGY PROGRAMS

Recommendation: Establishment of an ACS approval service for Chemical Technology programs.

Chemistry programs of two-year colleges are not among those eligible for the review and approval system for undergraduate pre-professional instruction carried out by the American Chemical Society's Committee on Professional Training. The review of such programs by regional accrediting bodies or by state two-year college boards is usually cursory, may be minimal, is often carried out by persons who have neither science nor chemistry background, and is not done with respect to guidelines that have been accepted or generated by the chemistry education community.

We believe that many benefits would flow from initiation by the American Chemical Society of a program approval activity directed to the needs of the two-year colleges. Institutions should have the opportunity, after careful internal self-evaluation, for external review of program, progress, and planning, by qualified chemistry educators working from guidelines developed and accepted by the chemistry education community.

Because of the great diversity of curricular needs addressed by two-year colleges, it is important that such a program approval activity develop gradually, covering first those curricula that are well defined, then those less highly structured.

T3. When the Revised Guidelines (T1) have been published and the outreach and consultation program (T2) is functioning, the American Chemical Society should undertake to certify/approve Chemical Technology programs in two-year colleges at the request of such institutions.

a. Like the present program of the ACS Committee on Professional Training, this activity in support of quality chemistry education in the two-year colleges should be voluntary on the part of the institutions and based on curriculum guidelines and review procedures that have been developed carefully and sensitively by highly qualified chemistry educators working closely with representatives of a cross-section of employers of chemical technicians.

b. A useful first step could be to offer the opportunity to two-year colleges for external review of their own self-evaluations conducted in light of the published *Guidelines*.

T4: AMERICAN CHEMICAL SOCIETY APPROVAL OF OTHER TWO-YEAR COLLEGE PROGRAMS IN CHEMISTRY

Recommendation: Development of an ACS approval service for college transfer and other two-year college chemistry programs at the request of such institutions.

Chemical Technology programs are relatively few in number and there is some agreement as to their level and content, though all of which we are aware interact flexibly with local and regional employers to assure a reasonable match between specialized components of the programs and the re-

quirements of changing employment opportunities. The college transfer programs offered by two-year colleges are much more numerous and are influenced in much more detail by the necessity to maintain reasonable correspondence between their content and that of related programs of instruction in the colleges and universities to which students transfer at the end of one or two years. When students may transfer to any of several institutions, as is almost always the case, the demands made upon the ingenuity and skill of two-year college faculties are considerable.

Because of this pluralism and variety, many have discouraged the Society from extending to the two-year colleges the kind of *direction* and assistance implied for four-year institutions by the *Guidelines* of the ACS Committee on Professional Training. But, because two-year colleges are a part of the higher education system that eventually graduates baccalaureate chemists, we believe that that extension should occur—and on the same basis: at the invitation of the institution, when it has determined that it wishes to be rated against the appropriate guidelines.

T4. When Recommendations T1, T2, and T3 have been implemented, the American Chemical Society should undertake to certify/approve college transfer and other chemistry programs in two-year colleges at the request of such institutions.

Recommendations on UNIVERSITY AND COLLEGE CHEMISTRY AND SCIENCE

U1 College Admission Requirement in Science
U2 College Graduation Requirement in Science
U3 Chemistry Courses for Nonscientists
U4 Reduction of Cultural Duality; Interdisciplinary Integration
U5 Laboratory Instruction in Foundational Chemistry Courses
U6 Chemistry Courses for Undergraduate Nonchemists
U7 Chemistry Modules for Professional Curricula
U8 Laboratory Experience in the Chemistry Curriculum
U9 The Approved Curriculum in Chemistry
U10 Characterization of Career Opportunities in Chemistry
U11 Mission and Structure of the ACS Committee on Professional Training
U12 Information Management

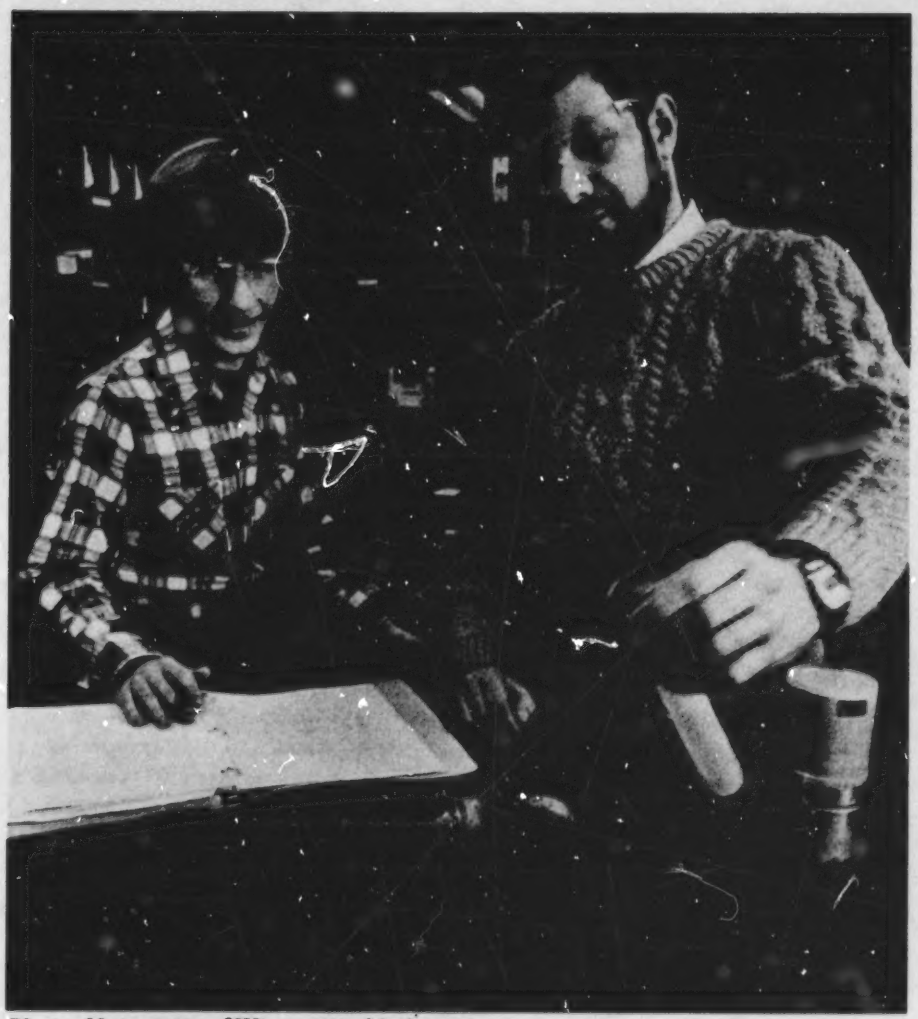

Photo: University of Wisconsin, Madison

[. . . a chemistry course] should represent a significant intellectual challenge; it should present substantial information on the properties and reactions of real materials . . .

U1, U2: COLLEGE ADMISSION AND GRADUATION REQUIREMENTS IN SCIENCE

Recommendation: National effort to attain acceptance of a requirement for admission to colleges and universities of at least 3 years of laboratory science and 3 years of mathematics taken in grades 9–12.

Recommendation: National effort to assure that the laboratory science requirement for any baccalaureate degree is at least 10 percent of the undergraduate credit that must be earned by the student.

The thoughtless early specialization and strong vocationalism that now characterize both secondary and collegiate education in the United States have eroded many aspects of liberal education and deprive students of its life-long benefits. We are sympathetic to those who propose restoration to the school curriculum of real contact with more than excerpts from the great literature of the world (and not just in our own language), addition to it of significant exploration of the fine arts, and elimination from it of needless repetition of self-centering concerns; and to those who propose the corollary changes in the degree programs of colleges and universities. Further, we believe that both school and college curricula need substantial strengthening with respect to other liberal and liberating arts—the sciences and mathematics.

In a preceding section devoted to the high school, (Recommendations H1–H5) this Task Force has urged strengthening of offerings and requirements for high school graduation. At the college level, too, there is presently a lack of desirable emphasis on foundational work in technical and scientific subjects. A survey by the National Research Council indicated that an average of 7 percent of undergraduate course work was required to be devoted to the natural sciences in 1930; compared with over 9 percent in 1967. Both high school offerings and college requirements drifted downward in this period, the former more rapidly than the latter.

This trend must be reversed if graduates of schools and colleges are to be prepared for the world that actually exists about them, a world that is increasingly dependent upon and reflective of science and technical endeavor. Many college graduates lack the background to deal with the technical aspects of some of the complex and major issues confronting contemporary society. Issues such as disposal of toxic wastes, environmental quality, occupational safety, nuclear power, and manipulation of genetic material, involve decisions by government. Ultimately, the government is the people and they should be both aware and informed. Most sciences, chemistry among them, relate to these issues. Even more important however, is the study of science as a powerful method of inquiry into the nature of the world about us.

A general increase in science requirements for college entrance would have a very desirable positive effect on secondary school curricula and graduation requirements. A general increase in distribution requirements for all college students would enlarge the science knowledge of a still growing, better educated group of the population, providing them with genuine understanding of the nature and content of science and increasing their capacity for discernment, critical evaluation, and sound judgement where science is a factor. Language and literature may be under pressure as major components of liberal education, but science and mathematics have yet to be accorded the recognition and study appropriate to their significance in the contemporary lives of society and the mind.

U1. The National Council (N1) in concert with the American Chemical Society and other science and engineering societies should work with national and state educational agencies, educational consortia and accrediting bodies, and precentor colleges and universities to attain acceptance nationwide of a requirement for admission to all colleges and universities of at least three years of laboratory science and three years of mathematics taken in grades 9–12.

a. We recommend that this science requirement be increased gradually to four full years of secondary school (grades 7–12) laboratory science, to include both chemistry and physics. We recommend that the mathematics requirement be increased gradually to four full years of secondary school mathematics, to include two full years of algebra. And, increases in content and achievement are the objectives, not just increase in time spent. The continuing downward drift in the fraction of credit in science offered in satisfaction of requirements for baccalaureate degrees is not in the national interest.

U2. The American Association for the Advancement of Science in concert with the American Chemical Society and other science and engineering societies should work with national and state education agencies, educational consortia and precentor colleges and universities to assure that the amount of laboratory science required for any baccalaureate degree is at least 10 percent of the undergraduate credit which must be earned by the student.

U3: CHEMISTRY COURSES FOR NONSCIENTISTS

Recommendation: Establishment of guidelines to the appropriate balance in college-level chemistry coures for nonscience majors among the fundamental principles of chemistry, applications of chemistry, and the place and role of the chemical sciences in contemporary society.

It would be an empty gesture to increase college graduation requirements in science without taking steps to assure that sound, informative, interesting, and useful courses exist to be applied to the requirements. Generally, introductory courses intended for science students or, worse, for majors in the field of the course, fail to meet the needs of majors in nonscience fields. Such courses assume both more background and more interest than the general student should be expected to bring to them; they tend to be narrow and detailed, strongly-focussed, and swiftly-paced; they discuss the trees and not the forest.

The decade ending in 1977 yielded almost 150 reports in the *Journal of Chemical Education* alone on curriculum and course developments in chemistry intended to meet the needs of the general student; many additional reports have appeared since that time. Some of the special courses described in these reports are elementary, non-mathematical versions of the standard introductory courses offered to science-oriented students; some have a strong "applied" or "environmental" orientation; and some focus narrowly on key topics such as forensic science, popular drugs, kitchen chemistry, or art and antiquities.

Critics of the special courses have argued that many of them fail what ought to be their central objective, to illustrate the nature of science and scientific thought, because of overemphasis on facts and underemphasis on process and methods. Others are found wanting because they avoid mathematics and abstraction, in spite of the fact that it is virtually impossible to gain admission to a college or university in the United States without a year of algebra and a year of geometry in one's secondary school program.

The Task Force applauds the interest and energy which have gone into these attempts to meet the needs of the general college student. It would be a mistake to strive for a high degree of uniformity in such course offerings simply because the national interest, as well as personal interests, were served by increased understanding of the sciences. However, we do argue that a chemistry course for non scientists ought to have certain hallmarks: it should represent a significant intellectual challenge; it should present substantial information on the properties and reactions of real materials, particularly substances that students might be expected to encounter in the ordinary course of affairs; it should show how models and hypotheses are used to organize and interpret such information, leading to the establishment of principles and "laws" of chemical behavior; it should emphasize the experimental, tentative, open-ended, and falsifiable nature of chemical knowledge, and provide examples of coherence, logical extrapolation, ambiguity, and irrelevance; and it should include material on both the historical origins of the discipline and its present societal significance. It should not be trivial, condescending, patronizing, or apologetic, nor should it be at high dilution or without rigor. In the words of V.V. Raman:

> " . . . (it) should be taught not simply as a body of useful knowledge clothed in technical vocabulary but as a mode of inquiry into the nature of the perceived world, as an intellectual framework to guide us in the adoption of tentative interpretations of what is observed, and as a world view that is not ultimate truth but is applicable only in the context of a given set of available facts . . . (It) should be taught because of the value system it fosters, because of its criteria for the acceptance of points of view as valid propositions—not because of its potential exploitable results, or even for its beautiful and powerful theories."

U3. An American Chemical Society Task Force on Chemistry Education for Nonscientists, which might be the body described in N4 or an ad hoc sub-unit of the Society Committee on Education, should consider the general and diverse aims of college-level courses taught for nonscience majors and establish broad guidelines to the appropriate balance in such courses among the fundamental principles of chemistry, the methodology and philosophy of the disciplines, applications of chemistry, and the place and role of the chemical sciences in contemporary society.

a. After guidelines are available, the Society, with assistance of other funding sources, such as the National Science Foundation and private educational foundations, should sponsor workshops for the creation and improvement of chemistry courses for nonscience majors (whose needs might be met more effectively by offering them sophisticated courses as seniors instead of introductory courses when they are freshmen).

b. In both the pre- and post-guideline periods, the Education Division of the American Chemical Society, or a unit like the Institute for Chemical Education (University of Wisconsin-Madison), could assist the improvement of such course offerings by establishing a clearinghouse for the exchange of syllabi, instructional modules, and other information.

U4: REDUCTION OF CULTURAL DUALITY; INTERDISCIPLINARY INTEGRATION

Recommendation: Development of workshops and other activities to increase interaction among teachers of the natural sciences and engineering, the arts, humanities, and the social sciences.

Improvement of the science literacy of students, especially at the college level, may depend on the simultaneous and *joint* improvement of other literacies. Science faculty in general and those in chemistry in particular often insulate themselves from the nonscience academic community, just as, in our view, the nonscience academic community is insulated from us. Unless there is better integration of science and chemistry with the totality of the intellectual enterprise, renewed emphasis on science awareness and literacy could simply widen the gap between the "two cultures."

The academic year does not provide enough opportunity for those who teach in very different disciplines to exchange viewpoints on issues of common concern with an eye to the development of integrated multidisciplinary instruction centered on them. Natural scientists, engineers, humanists, social scientists, and those in the arts all have contributions to make to our understanding of matters such as: the interaction between science and literature; the impact of technical activity on the human and physical environments; ethical consequences of the application to human beings of the findings of molecular biology and genetic chemistry; the philosophical implications of modern physical theory; uniqueness in the universe; profits and prophets; preservation of the past; and other similar topics, without limit.

Some of the Chautauqua-type short courses sponsored by the National Science Foundation have brought scientists and nonscientists together to learn about progress in areas such as the history of science, research in cognition, and the social consequences of the computer revolution—all of which bridge the gap between the two cultures. We applaud this program and urge its expansion. But more extensive activities of a similar orientation are necessary to accelerate this integration.

U4. The National Council and the supporting societies mentioned in U1 should promote the development and establishment of a program of summer workshops and other suitable mechanisms to bring together teachers of chemistry, other natural sciences, engineering, the arts, humanities, and the social sciences, to study issues of common societal and intellectual concern so that the fruits of such study may be applied directly to the improvement and expansion of multidisciplinary instruction.

a. Some of these workshops could augment the series sponsored currently by the National Endowment for the Humanities; others could be part of existing National Science Foundation programs; and a new series designed specifically to bridge the gap between the "two cultures" might usefully be sponsored jointly by these two agencies. Such programmatic expansion should be deliberate, long term, and guided by thoughtful evaluation.

b. Additional support for the faculty members participating in these workshops should be expected not only from their institutions but from the various academic discipline societies and associations.

U5: LABORATORY INSTRUCTION IN FOUNDATIONAL CHEMISTRY COURSES

Recommendation: Adoption of a standard that all college-level foundational chemistry courses, whatever their student clientele, include substantial and significant laboratory work.

"When we shall be able to employ in scientific education, not only the trained attention of the student, and his familiarity with symbols, but the keeness of his eye, the quickness of his ear, the delicacy of his touch, and the adroitness of his fingers, we shall not only interest . . . people who are not fond of cold abstractions, but, by opening at once all the gateways of knowledge, we shall ensure the association of the doctrines of science with those elementary sensations which form the background of all our conscious thoughts, and which lend a vividness and relief to ideas, which, when presented as mere abstract terms, are apt to fade entirely from the memory." [James Clerk Maxwell (1831–1879), physicist]

The discussion preceding Recommendation H5 presented an outline of the case for the laboratory component of high school chemistry. Since scientists must "do" things as well as think about them, there has been no lack of recognition of the importance of laboratory work at every stage of *their* education. But, the laboratory is a similarly essential component of foundational instruction in science intended for (and especially if required of) those preparing themselves in disciplines outside the sciences. The case is the same at the collegiate level as in the secondary schools: science is experimental; human beings gather data, interpret it, and organize it; the interaction in the laboratory between nature and the student is an essential ingredient of education.

U5. Whether they are taught to nonscientists, science majors, or chemistry majors, foundational courses in chemistry at the college level must include a substantial component of significant laboratory work.

a. "Substantial" is ordinarily determined locally. But, it is our belief that devotion of less than 30% of scheduled time to the laboratory work in a foundational course is close to if not actually insubstantial. It is of paramount importance that any educational laboratory work be *significant*, not merely trivial or time-spending.

U6, U7: CHEMISTRY FOR NONCHEMISTS

Recommendation: Preparation by the ACS Committee on Professional Training of recommendations concerning the content of chemistry courses intended for students who are not majors in chemistry.

Recommendation: Development by ACS of curriculum modules in such aspects of chemistry as are germane to the curricula of professional schools in law, business, and the health professions, among others.

We believe that the study of chemistry is good intellectual exercise and that it imparts much knowledge of permanent value and wide applicability; it is, therefore, useful preparation for almost any career. Indeed, it is the centrality of chemistry that makes it a required subject at the introductory level in a large number of science and nonscience curricula. However, chemistry course enrollments in most colleges and universities diminish rapidly as their level rises. Some technical and professional curricula require a second year of chemistry, building on the General Chemistry course that is taken, usually, in the freshman year; but, very few undergraduate students other than chemistry majors are found in the advanced courses which depend on "second year" courses in organic and analytical chemistry and the necessary parallel work in physics and mathematics. Most of the instruction in chemistry departments is for the benefit of students who do not intend to major in chemistry.

Many students who take chemistry because it is prescribed by the curriculum for another major feel "sentenced" to serve out the experience. In

some cases the fault lies in the chemistry department: it may have allowed its service activities for other units to get out of tune with their needs; or, it may have gone too far in tailoring such offerings to narrow interests, robbing the study of chemistry of its breadth and vitality. In some cases the fault is wider spread because there is insufficient knowledge on campus of national trends in chemistry requirements of the major professional curricula other than chemistry—in the health professions, for example. In all cases, we believe, the interaction between provider and consumer departments could be improved if guideline information were available from a source committed to the maintenance of quality in chemistry instruction by other disciplines. That source exists: it is the Committee on Professional Training of the American Chemical Society.

U6. The American Chemical Society's Committee on Professional Training, in cooperation with its counterpart bodies in the professional societies serving other disciplines, should make recommendations concerning the level and content of college chemistry courses for students majoring in fields other than chemistry, especially other technical fields.

a. This activity is proposed as an aid to the necessary continuous interaction between chemistry and other departments, not as a substitute for it.

The slow decline in number of undergraduate majors in the liberal arts, of which chemistry is one, has had at least one very undesirable effect: students carrying out advanced work in non-science fields and in preparation for the professions now frequently lack the necessary background in chemistry and other sciences that, formerly, they would have acquired early in their undergraduate years. In a few areas a whole course in chemistry (or another science) would repair this omission; in most others less time is available and more specific content is required.

U7. The American Chemical Society, through the body described in U3, above, and with the assistance of various of its membership Divisions (e.g. Chemistry and the Law; Chemical Marketing and Economics), should undertake to determine the needs and develop curriculum modules for advanced instruction in such aspects of chemistry as are germane to the curricula of professional schools in law, business, and the health professions, among others. The Society should join with other science societies to develop similar but more general modules in science, its content, and its methods.

U8: LABORATORY EXPERIENCE IN THE CHEMISTRY CURRICULUM

Recommendation: Inclusion in the budgets of instrument purchase programs of additional funds to permit development of cooperative mechanisms for the maintenance and repair of such equipment.

There is widespread concern that both the quantity and quality of laboratory experience in baccalaureate degree programs is decreasing. The requirements for formal laboratory work have always been less in the United States than in other industrialized nations, but increasing costs of modernization, upgrading, or even sustenance of present levels of quality generate pressures which are resulting in even less favorable comparisons than before. Many students awarded bachelor's degrees in chemistry have very limited experience with modern laboratory techniques and even less experience in the design, formulation, conduct, and analysis of experiments. (Students graduating from Cooperative Education programs are a notable exception.) As the content of the chemistry curriculum has become more theoretical, more student time is spent in the classroom and in the pursuit of solutions to formal problems, and less in the laboratory learning and perfecting those techniques which establish and maintain the real contact of a chemist with the material world. Students develop little feeling for the behavior of matter—which, ultimately, is what chemistry is all about.

The advent of the computer has placed additional pressures on laboratory instruction. It sings the siren song of economy through simulation, with additional benefits of tirelessness, cleanhandedness, and freedom from chemical hazard. These attractions (instead of those such as augmentation of the laboratory experience, increase in the scale and sophistication of related data reduction, and the development of broader

and more challenging experiments) seem to affect the ways in which the computer is applied in the laboratory. Thus misapplied, the computer becomes another force driving students farther toward the view that chemistry is a game played against skillful opponents (who already know everything that the student is supposed to learn) rather than a way of unraveling and comprehending natural phenomena.

For over twenty years, one of the most effective responses of chemistry educators to the disinclination of students to regard laboratory work as important has been to bring such supervised experimentation closer in methodology and sophistication to the ways that chemistry is practiced in real career situations. At first, experiments in advanced courses were designed to use instrumentation like that used in academic or industrial research; later, as less expensive and more sophisticated versions of these instruments became available, this kind of exercise spread to less advanced courses. The cost escalation of the past ten to fifteen years threatens to wipe out these earlier gains.

The initial cost problem has been attacked successfully by a host of programs. These include industrial donation to education of still useful instruments, and several instrument purchase programs supported generously in past years by the National Science Foundation. Instructional and research instrumentation programs for colleges and universities have helped the improvement of laboratory instruction, as have those which stimulate and support undergraduate and faculty research opportunities. Reinvigoration and expansion of these programs is necessary if the American chemistry graduate of the future is to be capable of the practice and not just the contemplation of chemistry.

One aspect of instrument-basing of laboratory instruction (and research, for that matter) has received much less attention than it deserves, especially if one believes that conservation of resources is an appropriate response to increased competition for resources. That aspect is the repair and maintenance of the complex and sophisticated instruments used in research and instruction. One need not visit a Third World country to see costly instruments out of use because they cannot be repaired. The problem exists even in research universities, where cuts in support staff seem to occur in perfect synchrony with the breakdown of equipment; but it is disablingly serious in smaller colleges and universities which have never been able to budget adequately for in-house maintenance and repair of instructional instruments.

Historically, agencies that grant funds to assist the purchase of instruments and complex equipment for use in education have regarded the maintenance and repair of such items as an institutional responsibility—part of "cost sharing." However the accountants feel about such things, something must be done to assist smaller colleges and universities in keeping their instruments on line. If the demand for direct subsidy of maintenance costs is to be restrained, other ways of addressing the problem must be devised.

The attention of the Task Force has been drawn to several approaches to meeting this need. Some colleges and universities close to each other have been able to share instrumentation and thus reduce the scope required of both initial purchases and later maintenance. In a few cases, industrial research laboratories nearby have made their instrument repair staffs available, such cooperation being a component of a broader academic-industrial collaboration. There are several instances of other kinds of inter-institutional cooperation. An especially attractive one (because of its continuing success) is that centered on Georgia Institute of Technology, which cost-shares with 60 smaller institutions a service designed to take Institute instrument repair specialists to where the trouble is.

U8. The National Science Foundation and other agencies supporting the purchase by colleges of instructional research instruments should include in the budgets of these programs additional funds to permit experimentation, demonstration, and implementation of cooperative mechanisms for providing maintenance and repair service for such equipment.

a. Since much government support of instrument purchases is tied to their use in faculty and undergraduate research, we urge that realistic note be taken of the differences in the professional situations of the faculty member in a small college and one in an institution geared to graduate education and research in making awards for the support of the general costs of research. More than one person has pointed out to us that the small college faculty member who carries on a program of research with undergraduates "produces good graduate students in chemistry, not necessarily publications."

U9: THE APPROVED CURRICULUM IN CHEMISTRY

Recommendation: Sponsorship by the ACS of the preparation of position papers providing advice and guidance to faculty members on ways to include or improve instruction in the undergraduate curriculum on a number of specific topics and areas.

Some of the strength of undergraduate education in chemistry in the United States arises in the multiplicity of opportunities available: a student can choose a college and a program that fits his or her interests and needs. At graduation, however, the interests and needs of potential employers enter the picture. Difficulties occur when the preparation of a student differs substantially from that which is appropriate and expected. The reduction of such difficulties is what has impelled the design of curricula whose content and, one hopes, intent are agreeable to the parties on either side of the meeting point.

The Committee on Professional Training of the American Chemical Society was established to determine and to promulgate "minimum standards" for the education of a baccalaureate chemist to practice chemistry as a professional. Over time, the "minimum standards" have given way to "guidelines," in recognition of the pluralism of both the academic community and the world of professional activity, but the Committee's program continues to provide assurance that graduates of an approved curriculum are qualified to function as chemists at a baccalaureate level of professional preparation. The Committee undertakes to understand what a chemist is supposed to be able to do and to enunciate the characteristics of the undergraduate education that will prepare one to be a chemist.

There has always been strong opposition to almost any position taken by the Committee, especially from schools that did not conform to the mold (it is a rather elastic one) deemed proper by the Committee. Fortunately, the Committee has limited its efforts to the publication of a list of "approved" programs that meet its guidelines. It has never forced an approved program on all the students in a given college; but it has insisted that all schools with approved programs be prepared to offer and, in fact, do offer a curriculum of that character and scope. And, application for approved status is completely voluntary on the part of an institution with a program to be considered.

We deal in other sections with some broad aspects of the structure and work of the Committee on Professional Training. Here, our concern is finer detail—the content of the approved curriculum—and it responds to opinions expressed by educators, employers, *and* students. Some feel the curriculum described by the Committee's guidelines is so rigid as to inhibit desirable experimentation and innovation; others would prefer greater specificity, especially if the curriculum included thereby some area felt to be neglected. Some feel that the curriculum is already overcrowded and needs purging; others believe that the cavities in the curriculum are more harmful than its bulges.

The following brief paragraphs will serve to identify some of the concerns expressed to the Task Force and shared by some of its members.

Courses concentrate increasingly on chemical principles that underlie current chemistry research and, to a lesser extent, practice. The result has been a weakening of *historical perspectives and humanistic values* in terms of which all chemistry majors should be prepared to understand the place of chemistry in our culture.

The full-year *organic chemistry and physical chemistry* courses are utilized (particularly in the large universities, which set the content and tone for nearly everyone else) by more students majoring in fields that build on chemistry than by those majoring in chemistry itself. Yet, as these courses have evolved they have tended to concentrate increasingly on topics that have microscopic orientation (fine for future graduate students in chemistry) to the exclusion of those that have a macroscopic orientation (needed by all others who are enrolled).

Much student interest in chemistry stems from contemporary applications to the life sciences. There is not space in the chemistry major's curriculum for much formal instruction in *biochemistry* and *molecular biology*, so room must be made for them in *organic chemistry*.

Most chemists are employed by industry, and most such deal every day with some aspect of *polymer and macromolecular chemistry*, topics which are coherent and mature. Both are almost ignored in the curriculum in spite of their critical relevance to career opportunities and the ease of their incorporation into courses in analytical, inorganic, organic, and physical chemistry.

There is a widening gap between academic coverage and career practice in the applications of *computers and computation* to the management of information, control of experiments, and development of models in both chemical research and nonresearch activities. Since computer-assisted instruction and experimentation are commonplace in colleges and universities, the problem is one of balance, not one of exposure.

Students see limited applications of *probability and statistics* in topics ranging from the kinetic theory of gases to the x-ray determination of

protein structure. Yet, examination of chemistry curricula shows virtually no formal coursework on mathematical probability or, even more important to a practicing chemist, on the statistical design of experiments, reduction of data, or the deduction of conclusions.

Chemistry faculty must share the burden of a criticism heaped on the whole of education: that its graduates are deficient in *communication* skills—inept at expressing their ideas or reporting the results of their work either orally or in writing.

Chemical economics is not part of the approved curriculum, yet economic factors will determine the course of the professional lives of most chemists. Good text material that could be incorporated in a variety of courses that *are* in the curriculum is readily available.

Most chemical educators and graduate chemists are aware of safe methods for the conduct of experiments and have some knowledge of how to handle emergencies Unfortunately, practice lags far behind awareness and formal instruction is virtually nonexistent. Education with respect to *safety and chemical hazards* should start with the early development of sensitivity to the problems, illustrations of good practice, and insistence upon it.

Formal training in *chemical information retrieval* is seldom included in the chemistry curriculum, yet every professional chemist must use a variety of complex printed sources as well as an increasing number of computerized databases. Further, the pace of change in information systems is greater than can be accommodated by self-help efforts.

Since chemistry is a growing, changing, evolving science, it should surprise no one that curriculum issues such as those just described continue to arise. The time available for baccalaureate professional education is relatively inextensible, however, and curriculum change must procede by evolution, substitution, and re-synthesis rather than by addition and accretion. We suspect that the Committee on Professional Training has considered relatively recently all of the curriculum problems mentioned above and more, yet the impression held by many is that nothing is being done.

The Task Force believes that it is possible to discover ways of bringing into the existing curriculum appropriate content from problem areas like those listed above. The problem is more one of pedagogy, the work of faculties, than it is of standard-setting, the work of the Committee on Professional Training. A useful model is the resource volume on physical chemistry topics important to chemical engineering students presently in preparation under ACS sponsorship. This volume derives from much person-to-person discussion, several symposia, and a working conference of physical chemists and chemical engineers (from both the industrial and academic communities) interested in solving the problem.

U9. The Society Committee on Education of the American Chemical Society and the ACS Division of Chemical Education should sponsor symposia and carefully defined and designed studies to examine a number of specific problems with the approved (professional) curriculum, and with those of its components that are utilized regularly by students majoring in other science fields. Among such problem areas are the following: historical perspectives and humanistic values; the organic chemistry and physical chemistry courses; biochemistry, molecular biology, and organic chemistry; polymer and macromolecular chemistry; computers and computation; probability and statistics; communications; chemical economics; safety and chemical hazards; and chemical information retrieval. These studies should generate resource materials and position papers to provide advice and guidance to college and university faculty members on optimal ways to improve or include appropriate instruction in these areas in the curricula pursued by chemistry majors and by students in other fields of science.

U10: CHARACTERIZATION OF CAREER OPPORTUNITIES IN CHEMISTRY

Recommendation: ACS consideration of how best to characterize opportunities in chemistry and the expectations of employers, identify necessary curriculum and resource elements, and utilize results of research to improve chemistry education.

At the present time, over 85 percent of all baccalaureate degrees in chemistry are awarded by colleges and universities on the Approved List of the ACS Committee on Professional Training. Of all baccalaureate chemists, about 40 percent move immediately into fields with other names, though they may be very close to chemistry (e.g.

medicine, agricultural chemistry, chemical engineering). The 60 percent of bachelor's degree recipients who retain the label *chemist* split about equally into those who go on to advanced work in chemistry or closely allied fields, and those who enter (or return to) industrial employment immediately. Since it has been half a century since a majority of doctorates in chemistry sought careers in education, it is no error to conclude that at least 96 percent of each year's group of graduating chemists will seek and find professional employment that is not academic but industrial or like industrial.

Organizations and corporations that employ many persons educated as chemists ordinarily support broad scientific programs. They can accumulate specialists of various sorts to achieve any flexibility and diversity that may be required in the lower levels of their organizations, but most promote quite significantly on the basis of the way in which an individual acquires that flexibility and diversity of professional competence within himself.

Employers of small numbers of graduate chemists tend to have more specific needs, and the match of organizational and personal specifics is often important. But small organizations have low institutional inertia—their needs can change dramatically in short times. Individuals must be able to adapt to such changes.

The wide spectra of career aims (for individuals) and opportunities (from employers) force impossible objectives upon the prescription of any curriculum other than those that provide maximum possible flexibility consistent with wise guidance of student learning. Although the Committee on Professional Training has attempted to follow this concept, the compromises it has been forced to make have led to what most of its critics and some of its friends describe as a degree of specificity that may be contrary to the interests of many students and in poor tune with the longer-range needs of those who will be their employers.

Some colleges and universities permit and even encourage chemistry students to graduate without satisfying the full requirements of the curriculum spelled out by the Committee; others simply ignore the rubrics of the curriculum (still specified in terms of "courses" and the "traditional areas" of chemistry) and operate their own educational patterns within the scope of "equivalent experience." Yet, whether its guidelines are obeyed or not, the Committee has a powerful and earned presence and reputation and its careful pronouncements are heard and learned, if not followed consistently.

Issues like those implied by the comments appended to the text of the preceding recommer dation are undoubtedly discussed by the Committee and acted upon by them. Yet, there is little information available about those process aspects and the same concerns are expressed repeatedly over time.

Expression of these concerns may represent partial answers being offered to the question "What is a chemist?"—a question that the Committee on Professional Training has continuously before it. The vitality of the chemical sciences guarantees that that question can never be given a single definite answer—even though the Committee discharges one of its major responsibilities by describing a single curriculum.

The Task Force believes that it is appropriate at this time, when the practice of chemistry is changing rapidly and increasingly diverse pressures operate on colleges, for a substantial effort to be undertaken to determine the kind of preparation which might fit students best for careers in chemistry as well as careers in related areas. This effort might profitably be approached from the perspective of the career itself, rather than from that of the educator who may have a limited view of careers related to chemistry as they actually exist. One is faced immediately with the fact that there is a broad spectrum of careers in- and based on- chemistry, and that they might require equally diverse preparation on the part of the future professional. It is for this reason that we feel the first step should be to determine how to characterize careers related to chemistry and to identify, insofar as possible, the kinds of professional education needed to prepare for them.

We would like to have the Committee on Professional Training undertake this effort itself, but recognize that it is a considerable task that the Committee might not be able to manage along with its other commitments. Therefore, we propose an ad hoc body to undertake this study—one that will take advantage of the experience of the Committee, but which has a broader base in both the academic and industrial communities.

U10. The Task Force recommends that the President and Chairman of the Board of the American Chemical Society either select an existing committee of the Society (perhaps the Society Committee on Education with some augmentation of membership) or appoint one ad hoc to consider how best to: (a) characterize opportunities in chemistry and the expectations of employers; (b) identify necessary curricular and resource elements; and (c) utilize the results of research on teaching, learning, and instructional technology to improve the effectiveness of chemistry education. This committee, whether selected or appointed, should include: (1) current members of the Committee on Professional Training (CPT); (2) former members of CPT; (3) representatives of a range of types

of industrial employers of chemists; and (4) members of the Society who have not been associated with CPT.

By *opportunities in chemistry*, we mean those accessible to chemists at the four traditional levels of graduation—associate, bachelor, master, and doctor; by *necessary elements*, we mean those that, if not available, will constrain the career options of individuals completing each of the levels of education mentioned; by *improvement in effectiveness*, we mean such sequelae as will preserve and enhance the flexibility of curricula, broaden the opportunities available to graduates without sacrificing the quality of their educational achievement, improve the match between courses of study and the long range requirements of employment, and make the educational experience more efficient and satisfying.

a. Since the results of such a study are intended to complement the continuing deliberations of the Committee on Professional Training, the report should be directed to CPT after review by the Society Committee on Education.

U11: MISSION AND STRUCTURE OF THE ACS COMMITTEE ON PROFESSIONAL TRAINING

Recommendation: Consideration of the mission of the ACS Committee on Professional Training.

Several sources of potential new responsibilities for the ACS Committee on Professional Training can be identified at any given time. For example, in addition to this Report (which proposes a number of new tasks for the committee, some continuing, some ad hoc) individuals and institutions propose regularly that CPT undertake the same kind of supervision of doctoral education in chemistry that it has exercised on behalf of that at the baccalaureate level.

At the present time, the time and effort of the Committee on Professional Training appear to be devoted fully to maintenance of the Approved List of baccalaureate chemistry programs in college and universities. The changes that have occurred in the past decade in the professional practice of chemistry and sciences related to chemistry have expanded enormously this supervisory task of the Committee on Professional Training. Additional obligations, especially if they are continuing, may be beyond the capacity of the Committee to accept or discharge.

There are risks in asking CPT to do more than it now does. The Committee has an excellent reputation for objectivity and firm fairness. Over a long period it has discharged a sensitive and difficult task with unchallenged concern for quality, high integrity, and demonstrable openness. Conceivably, the imposition of additional obligations on the Committee could weaken the thrust of its present efforts—a result wished-for by no one.

The Committee itself can certainly determine whether or not its present duties permit its acceptance of one or more *ad hoc*, time-limited tasks (such as several proposed in this Report). But another body should provide advice on the assignment to it of additional permanent obligations.

U11. This Task Force recommends that the President and Chairman of the Board of the American Chemical Society assign to an existing committee of the Society, or to the ad hoc committee described in U10 above as its second major task, the responsibility to consider the intended, actual, and appropriate future mission of the Committee on Professional Training and to recommend such specific changes in mission, structure, or both, as may be required to maintain and extend the effectiveness of the Committee, whether continuing as at present or in some new form(s).

a. The report of the proposed committee should be reviewed by the Society Committee on Education and by the Committee on Professional Training. But, since its content may foreshadow changes in the assignment of CPT, the Board of Directors and the Council should be the ultimate recipients of the report.

U12: INFORMATION MANAGEMENT

Recommendation: ACS leadership of efforts to modernize the concept and structure of technical libraries.

Very early in its history, the American Chemical Society recognized a responsibility twin to that of reporting discovery and observation in chemistry—the responsibility to assist the management of the body of information thus created and expanded. The Society's *Chemical Abstracts Service* is the contemporary manifestation of that recognized and accepted responsibility.

Every chemist is both a creator and manager of information. Much of the formal education of a chemist is given over to activities designed to teach the state of the science and the basic techniques for adding to its store of knowledge. Some time (but less than formerly) is devoted to instruction and practice in the now burgeoning area of information management. Students do gain, almost osmotically, some ability to use the traditional repositories of fact and opinion—journals, books, abstracts, indices, patents, and the collections of them called libraries. But the advent of the computer has increased both the varieties of ways in which traditional collections can be probed and the rate at which new and possibly substitute kinds of collections are created, developed, and emplaced.

The ease in the speed with which computer techniques can be applied, and the continued rapid fall in computing costs, have resulted in the spread of new techniques that do not employ the human mind as intermediary, but apply selected data directly to the design, conduct, analysis, interpretation, and reporting of experiments. The trend is clear and will continue. But, since the costs, though falling, are still substantial, teaching of these techniques and practice with them is done less in colleges and universities than in the industrial laboratory.

The nature of the technical library is changing. No longer only a collection point, it is the center of manifold information gathering and management activities. Every discipline is contributing to this change; every discipline must be able to profit from it.

U12. The American Chemical Society should identify an existing committee or create a new one to provide leadership within the whole scientific community for analyzing the needs and opportunities and for proposing implementation nationwide of programs to modernize the concept and structure of technical libraries. This committee should draw on the expertise of Chemical Abstracts Service, but should include other individuals skilled in information science and the use of computers for information management in both the industrial and academic communities. Among the committee's concerns should be the use of these techniques for formal and informal education, and the training of individuals for careers in chemistry applications of information sciences.

Recommendations on CAREERS IN CHEMISTRY

C1 Economic Restraints on Career Development

C2 Arbitrary Restraints on Career Development

C3 Continous Learning

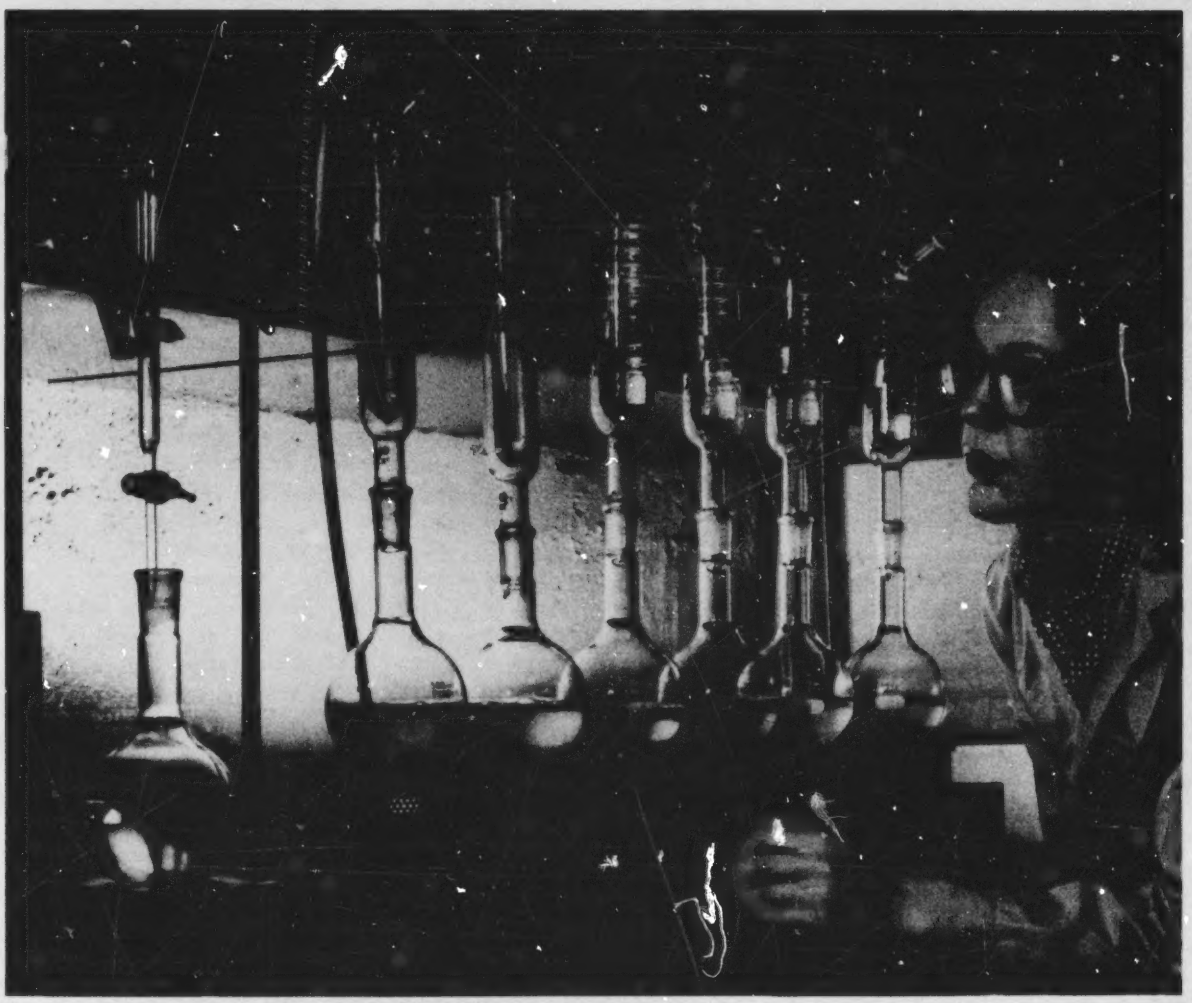

Photo: USS Chemicals—Division of United States Steel Corporation

The chemical sciences and chemistry education cannot achieve their maximum potential unless those who have the interest and intellectual capacity enjoy equal access to entry and advancement in chemistry and related disciplines.

C1: ECONOMIC RESTRAINTS ON CAREER DEVELOPMENT

Recommendation: Government and industrial support of a program of postdoctoral appointments for research on problems of national concern to assist bridging temporary differences in employment demand and scientist supply.

One of the hazards associated with defined pathways for professional preparation arises in the implicit assumption that the supply of graduates and the entry-level demand for their services will correspond. In comparison with the situation in the performing, graphic, and plastic arts, where there is virtually no market influence on the production of graduates and only a vaguely defined market for their services, that of the chemical sciences is comfortable indeed. It is believed that in the chemical sciences there is a reasonable balance between the supply and demand for new professionals, whose numbers are relatively stable, and that incentives provided by salary and other differentials will act quickly to smooth any imbalance.

Unfortunately, the rate of change in industrial employment needs is typically an order of magnitude faster than that of academic preparation of scientists at any particular level of education. For example, the ratio 1981/1983 of offers of entry-level positions was approximately 2 for Ph.D. chemists and 8 for B.S. chemical engineers, while the ratio of degrees awarded was essentially 1; and demand (new hires) tends to drop 3–5 times as rapidly as it rises. Further, economic driving of industrial demand causes fluctuations in both its scale *and* its composition; for the latter there are no quick-acting analogues in the educational stream.

An especially pernicious corollary to the mismatch between rates mentioned above is the paucity of recognized, experience-building interim positions for well qualified graduates who, through no fault of their own, enter the marketplace at a time of glut. When conditions improve the following year or perhaps the next, employers look at the current year's crop to the virtual exclusion of those passed-by in the preceding year or two. There is a premium on freshness for scientists as well as fish.

It is an appropriate national concern that there be developed a mechanism to dampen wide oscillations in the number of employment opportunities available to the number of scientists being educated today—a number which is in good balance with *long-term* average demand. The academic postdoctoral research position has served to provide further (sometimes additionally diverse) education to persons intent on academic careers; and the aggregate of such positions (which has grown steadily for several decades) provides useful interim employment for other new scientists when industrial demand is slack. But, if there is a mismatch between what universities produce and industry needs, postdoctoral positions in universities, by their very nature, do little to address it in a useful way. A national postdoctoral system that could provide the dampening needed should be centered outside academe. It is highly desirable that the number of such positions located in industrial, institutional, and government laboratories be increased. Although there are some temporary or revolving postdoctoral research appointments in industry, that sector, faced with the occasional necessity to cut back on the employment of scientists, has found it difficult to make a continuing investment in temporary, inexperienced scientists, though such an investment could permit an industrial laboratory to undertake research or development studies without long-term commitment to either programs or personnel—a kind of flexibility that industry seems to want (and academe ought to).

The various research and testing laboratories of Federal, state, and local governmental agencies employ large numbers of scientists on regular and permanent professional tracks. The Federal entities, at least, provide also a number of temporary or revolving postdoctoral research associateships (the recruiting competition for the program is administered by the National Academy of Sciences—National Research Council); the program, however, is small in comparison to need and, in spite of substantial effort on the part of some Federal agencies, almost unknown. The Task Force believes that this and similar programs should be better publicized and that they should be expanded, not in mission directions, but toward the solution of problems in applied science germane to matters of serious national interest—such problems have long-term industrial as well as governmental and disciplinary dimensions, and could maintain the "freshness" (for purposes of eventual industrial employment) of the young scientists who worked on them for, say, one or two years.

C1. This Task Force recommends that the United States Government establish a new program of postdoctoral research on problems of national concern which could support as many as 200 chemical sciences appointments per year in Federal, industrial, or institutional laboratories. Such appoint-

ments would be tenable for a maximum of two years, and their number an addition to those presently funded through grants for fundamental research. The American Chemical Society should assume leadership of an effort to secure parallel expansion of such appointments under industrial sponsorship and, in other ways, assist dampening of wide swings in the annual numbers of employment opportunities.

C2: ARBITRARY RESTRAINTS ON CAREER DEVELOPMENT

Recommendation: ACS sponsorship of efforts to identify and correct arbitrary restraints on women preparing for or practicing the profession of chemistry.

The chemical sciences and chemistry education cannot achieve their maximum potential unless those who have the interest and intellectual capacity enjoy equal access to entry and advancement in chemistry and related disciplines. This objective should be a basic principle of the chemical profession and should be both addressed and exemplified by the American Chemical Society.

Statistically, the members of some groups in the nation's population, though qualified individually, continue to be underrepresented in the chemical professions, particularly at the upper levels of career development; women and minorities still constitute only a small percentage of the total number of chemical scientists, especially in major universities and small corporations. This situation arose from historical patterns which, in turn, originated in arbitrary restraints on entry into the profession and on later advancement. Extensive efforts have been made to modify the old patterns, reverse their effects, and thus remedy the situation—but it persists.

Women are identified legally as a minority segment of our population. That they are, in fact, both an actual majority of the population and the largest of the legally identified minorities merely intensifies the reaction to the injustices experienced by women who pursue careers in fields long dominated by men.

Some of our informants, women among them, hold that serious discrimination against women no longer characterizes the chemical sciences. They argue that the present underrepresentation simply reflects the length of time it takes to change the perceptions and understanding of young women at the moments when career-related decisions are made; and they assert that there continue to be improvements in the career situations of women in chemistry.

Problems of women in chemistry are similar in many ways to those of other minorities; but, because they constitute the largest minority, a thorough study of their difficulties within the profession could have important teaching quality with respect to the problems of all minorities.

C2. The American Chemical Society, through its Women Chemists Committee and other appropriate bodies, should sponsor a conference to identify the difficulties encountered by women qua women in preparing for or practicing the profession of chemistry. Following that conference, a specific charge should be made to an appropriate Society body to seek actively solutions to these problems and removal of such arbitrary restraints on career development as may have been identified by the conference. If this approach proves successful, the Society should apply it to the difficulties in the same areas experienced by minority, handicapped, and other special segments of the profession and the profession-to-be.

a. The Task Force urges that the conference consider questions like the following:

Are there factors that operate currently to impede the recruitment and advancement of women in chemistry, or have such factors as existed in the past been eliminated?

Are there constraints associated with certain career paths that effectively inhibit women chemists from pursuing these paths?

Do such factors or constraints tend to steer women into careers that are less challenging or rewarding than those open to men?

Are there factors, real or perceived, that operate to discourage young women from choosing careers in the chemical sciences?

What should be done to change the patterns that discourage women students in grades 6 through 10 from making career decisions that reflect their earlier enthusiasms for science? In particular, what should be done to make chemistry an attractive career for women?

b. Since the problems that do exist are more because of the attitudes of men than of women, men as well as women should be involved in planning the conference, conducting it, and implementing its recommendations.

C3: CONTINUOUS LEARNING

Recommendation: Increased development, testing, and evaluation of electro-optical systems for continuing education; expansion of ACS continuing education services.

The tradition of continuing personal and professional education is a very old one in the United States. It has been sustained by the involvement not only of educational institutions but of professional societies, licensing boards, employer entities and groups, and individual providers. The purposes of such continuing education are almost as numerous as the individuals so engaged; but, the major categories, apart from cultural and educational enrichment in service of personal objectives, appear to be:

Maintenance: work intended to maintain and update the previous formal education of the individual; typically, such work is organized into "courses" similar to those taught in colleges and universities, and brings to the graduate professional the content and level of such instruction.

Completion: usually courses, but in areas which complement or supplement the work (in both major and minor fields of study) taken by the individual when a student: in the case of a chemist—a follow-up course in, say, physical chemistry; an additional, higher level course in mathematics or physics; work in economics, marketing, or business law missed during initial professional education.

Proficiency acquisition: the largest category and the most varied in mode and scale of individual activity: work designed to yield (through limited, often intense study) new or enhanced proficiencies in the use of new experimental techniques; report writing and technical communications; recent advances in methods, theory and practice; etc.

Continuing education is accomplished through a variety of formats: "open university"; correspondence; typical school, college, and university classes; less formal (and other) modes which involve just the individual student at the time of instruction; and tutorial and small group instruction. Twenty-five years ago, continuing education, like initial education, was delivered primarily though the printed or directly spoken word. More recently a host of electro-optical techniques have gained prominence (prerecorded audio and video materials, electronic blackboard and teleconferencing, and a number of different kinds of interactive, computer-based methods)—but with a trend favoring class or institutional settings.

The rapidly spreading use of electro-optical techniques, unlike the "blip" of "teaching machines" some years ago, exhibits such momentum that one must conclude that a revolution in educational technique is underway that will be as sweeping as that occurring in the workplace. In some colleges and universities there is concern that students no longer know how to learn from books, so acclimated have they become to nonprint presentations. Unless there is parallel development of new techniques affordable by individuals, continuing education in the future will be as place-bound as initial education has been and will continue to be. This would reduce the scale of such activity sharply, since much of continuing education is now accomplished on an individual basis and at home.

C3. Federal agencies, private foundations, and scientific societies concerned with support of education in science should devote substantial resources to the experimental development, testing, and evaluation of electro-optical technological systems for providing maintenance, completion, and proficiency acquisition types of continuing education, with special emphasis on the accessibility of high quality instruction to individuals away from the workplace. Specifically, the American Chemical Society, through its Education Division, should continue to develop and expand its self-supporting audio, video, computer-based, and other electro-optical continuing education services to both individuals and groups.

Recommendations on INDUSTRY AND EDUCATION

I1 Academic-Industrial Cooperation

I2 Coordination at the Industrial-Academic Interface

Photo: W. R. Grace and Company

The chemical industry can bring substantial human, intellectual, and financial resources to bear in aid of the structure and processes of education.

I1: ACADEMIC-INDUSTRIAL COOPERATION

Recommendation: Strengthening and expansion of activities that bring the resources of the chemical industry to bear on improvement and support of science education at all levels.

Historically, a variety of interactions between industrial and educational institutions made major contributions to the growth and eminence of the nation in pure and applied science; chemistry was the earliest of the sciences to enjoy this florescence. Some of these interactions have persisted during the last twenty-odd years (continuing education programs, consulting by faculty members, industrial support of some academic research, etc.), but many have shrunk or disappeared altogether as Federal funding of basic research, development in special areas, and support of many programs to improve science and technical education have put money into academic institutions on a grand scale.

Since the last century, academic scientists and industrial managers have dealt with each other as producer and employer, respectively, of the highly educated individuals needed by the private technical sector. This relationship has grown steadily in size and occasionally in tension. Private industry will never match, much less supplant, the scale or variety of Federal involvement in science education and academic research, but the recent redevelopment of common interests into shared and collaborative activities cannot but benefit all three—education, industry, and government.

Industry and business have the capability of contributing by participation in many of the formal structures and processes of science education, and the desirability of their doing so is becoming more generally accepted. Present educational modes can be supplemented with resources available from scientists and institutions outside the education establishment. Scientists employed by industry can provide professional skills as adjunct or exchange teachers at all levels of education, and can contribute in many ways to the development of a populace that is scientifically aware and literate.

The need for science literacy of the general public is beyond debate. Further, most of our local and national leadership are nonscientists, and their education for leadership must include adequate grounding in the content and methodology of science. Industry is a direct victim of a scientifically illiterate population.

In response to these needs, the chemical industry can bring substantial human, intellectual, and financial resources to bear in aid of the structure and processes of education. To the extent that industry recognizes that the future strength of our technological society depends on the present student body, industry will recognize that it is in its interest to divert a significant portion of *present* resources to the education of future generations of citizens and scientists.

In the course of this study, the Task Force has observed many instances of viable interactions between educational institutions and nearby industries. Some industrial corporations are sufficiently large that their participation in such activities extends well beyond the local scene to the state and region, and some operate at the national level. Where chemistry is concerned, the nationwide system of local sections (membership) of the American Chemical Society provides both a forum for planning and action and a natural mechanism for coordination that is *local* in the best sense of the word. In the paragraphs below are examples of local activities that could serve as models for widespread application.

Elementary Schools. Industries have recognized the need for sound education in the schools in many ways: creation of award programs for master teachers; opening plants and laboratories to guided teacher tours; establishment of special funds to purchase science demonstration and other unusual teaching equipment and supplies; support or award of scholarships to teachers taking science updating work at workshops, institutes, and in summer sessions at colleges and universities; providing their science personnel for special meetings, lectures, workshops, demonstrations, in-service courses, and other activities aimed at strengthening science education; participation in varied efforts to acquaint the public with the roles of science and technical endeavor in contemporary society; work to increase those aspects of public awareness that can result in improved local support for local schools; and sponsorship of teacher institutes and workshops on science teaching.

High Schools. Industry interactions with high schools embody all of the elements just listed and others in addition: donation of technical library materials; encouragement of industrial scientists to undertake part-time teaching or teacher assistance positions in high school science programs; establishment of special funds to acquire the laboratory equipment and supplies necessary to assure that students have high quality, up-to-date experiences in basic science; sponsorship of student science fairs and projects and related awards for excellent achievement; student tours of indus-

trial plants and laboratories to emphasize the variety of technical employment and assist guidance counseling in the schools; provision of summer appointments in research, marketing, technical services, personnel services, and other areas, for qualified science teachers (reported more frequently for chemistry than for any other science or technical area!); support for "career days" and other counseling activities to provide sound information to students on career choices and employment opportunities; provision of internships to science-interested students after high school graduation but before college to give them a taste of technical employment in industry, as well as remunerative summer employment; and support of ACS local section efforts to improve high school chemistry teaching.

Post-secondary. Community colleges, four-year colleges, and universities enjoy a still wider spectrum of interactions with industry, including all of the kinds mentioned above and the following in addition: donation, sharing, and exchange of research instrumentation; utilization of faculty research skills, as consultants and as summer and sabbatical employees; support for undergraduate summer research; participation in formal Cooperative Education programs for chemistry undergraduates; provision of pre-research summer appointments for chemistry graduate students; support of academic fellowships, graduate and undergraduate research assistantships, and teaching assistantships; development and support of continuing education programs for industry employees; establishment of discretionary funds in chemistry departments to support educational activities or purchases for which institutional funds are not or cannot be made available; exchanges of qualified scientists between industry and academe (adding to the experience and perspective of both); support of student travel to regional scientific meetings and to industrial plants, research, and development laboratories; funding of faculty research projects; support for faculty work on research of specific interest to an industrial sponsor; sharing of library resources; interconnection of computer systems; consultation on curriculum content and development for appropriate, accurate, and timely reflection of industrial research interests and needs; provision of instructional materials dealing with industrial research interests and needs; provision of instructional materials dealing with industrial processes and major product groups; and rostering the skills of retired industrial scientists.

This listing is by no means exhaustive, but it shows the breadth of activities which have developed in various places as local industries and educational institutions discover and act on their common and mutual interests.

I1. The Task Force recommends strengthening and expansion of the wide spectrum of activities that bring the resources of the chemical industry more effectively to bear on the improvement, support, and service of education at all levels. This expansion is important in technical areas, but it is critical in the wider domain of the public understanding of science. The local sections of the American Chemical Society are natural sources of knowledge, interest, talent, and energy for such efforts.

I2: COORDINATION AT THE INDUSTRIAL-ACADEMIC INTERFACE

Recommendation: Establishment of an ACS staff Office to deal with activities at the academic-industrial interface.

The text of the preceding recommendation (I1) contains lists of some of the ways in which the resources and expertise of industry are being brought to the service of education at various levels, and of some of the less conventional ways in which schools, colleges, and universities, and their faculties, are meeting the needs of industry and business.

No one is concerned about continuing exploration of industrial-academic interactions; for, after all, both sides of the interface are changing continually and their ways of relating to each other must also. Many are concerned, however, about the continued nature of much of this exploration—about its never-ending, repetitive, wheel-reinventing quality; the lists of recommendations from successive conferences on the subject often have 75 percent redundancy, even after application of a correction for cliches. For example, it is highly likely that sometime later this year (and probably next year as well) there will be a major conference exploring problems at the interface be-

tween the industrial and academic worlds. (The writer of this paragraph has attended four such conferences in the past eight years and been a speaker at two of them.)

One hopes for increase on a national scale of the number and scope of interactions like those described in the text of the last recommendation. Virtually all of those activities started at the local level, because there was communication between interested persons on both sides of the interface and ways were found to turn those interests into action. Earlier it was noted that local sections of the American Chemical Society can and do play important roles at this interface. An example of a new kind of effort is that of the Central North Carolina Section, whose Academic-Industrial Matrix (AIM) was created to coordinate and facilitate a wide spectrum of activities bringing academic and industrial chemists together to work on solutions of problems of mutual interest.

The governance structure of the American Chemical Society contains numerous bodies with interest in the interface: Corporation Associates; the Society Committee on Education; the Committees on Local Section Activities, Professional Relations, Project SEED, Professional Training, the Handicapped, and others—all working under the general oversight of the Board of Directors or Council. But, in spite of this extensive interest, concern and proctorship, the level of action is lower than we feel it must be.

12. The American Chemical Society should establish a staff Office to deal with the numerous and diverse activities at the academic-industrial interface, so that the resources and potential of both communities may be brought more effectively to bear on the improvement of both science education and the public understanding of science through education.

a. This staff function could be created simply by expanding that presently concerned with Cooperative Education, one of the most effective kinds of interaction between industrial and collegiate institutions. As the principal coordinating body for the Society's activities related to education, the Society Committee on Education should assume leadership in developing a proposal to the Board of Directors concerning the responsibilities, role, support and funding of such an Office.

b. An early task for this Office should be review of the recommendations of recent Society conferences and workshops on problems at the academic-industrial interface to determine which are being implemented and which are not. Successful implementation on the local level of suggested programmatic activities should be publicized and other local foci of interest stimulated and supported in their efforts to emplace such activities. Recommendations for new policies or modified statements of policy should be tracked and efforts made to assist the clearing of the docket.

c. The Office should devise strategies for using existing Society communications networks to disseminate information about successful efforts to solve problems at the interface and about new kinds of local and area attention to education that seem to be helpful, and in other ways should assist and reinforce local efforts.

MONEY

The various initiatives recommended by this Task Force would require both public sector and private sector financial support, directly and indirectly. In this section we indicate levels of expenditure that seem appropriate for the objectives of the highest priority recommendations.

The recommendations to the United States Government of highest priority have to do with improvements in the qualifications of teachers (A1) and in the quality of instruction (E5). The Task Force believes that a broad spectrum of in-service workshops, short courses, and institutes for teachers (A1) offers the best hope for improving and maintaining the qualifications of those who teach, at every level. While the NSB Commission on Precollege Education recommended a five-year effort of this kind, we believe that a smaller but permanent program is necessary. Over a period of 4 to 6 years, it should be possible to phase-in a program which would be staffed adequately and reach a reasonable fraction of high school and pre-high school teachers each year. The costs would depend on the mix of program durations and locations. We recommend that the direct and institutional indirect costs of instruction, as well as certain of the participant costs be provided by the Federal Government at a steady state annual level of $200-250 million. State sharing of the total costs of such programs would be expected through their support of released time, continuation and outreach efforts, facilities improvement, long term salary augmentation, additional funds for operations, etc.

A major factor in improvement of the quality of instruction could be the Federally-supported Regional Science Centers, an eventual 10 being proposed by the Task Force (E5). The focus of these Centers would be on materials and new methodologies, though activities in those areas cannot be divorced from concern for subject matter. An annual Federal expenditure of $10 million for these Regional Centers is recommended. A separate research and development center oriented specifically toward new instructional *technologies* should be created also; the recommended level of Federal support is $2 to $5 million per year. As these techniques become more widely dispersed in the schools, this particular center might acquire a more diversified mission and be regarded at least in part, as an eleventh regional center. [Both these aspects of the Center program were recommended by the NSB Commission.]

The highest priority recommendations by the Task Force that involve direct expenses to States are the raising of teacher certification standards in science and mathematics (E1, E4, and H2), related improvements in teacher compensation and conditions of employment (E4 and H2), and increases in the amount and level of science and mathematics taught to all students (E1, E2, H3, and H5). Full implementation of these recommendations would entail substantial costs to State education agencies and local school districts. Some of these would be direct costs: better facilities, additional laboratory instruction, higher pay for teachers in demand in alternative markets, increased costs for operations, etc. Some would be indirect costs: high expectations and standards (for people on both sides of the desk), increased certification requirements, improved conditions of employment, organizational changes, etc. Each state, municipality, district, and school has its own unique mix of problems and opportunities. It is not possible to make estimates of additional costs that are satisfying in their detail.

It is possible, however, to indicate an appropriate level of increased expenditure by focussing on annual expenditures per pupil. We estimate that the improvements in science instruction contemplated by our recommendations for the elementary schools could be bought for an annual additional expenditure of $100 per pupil, including a portion of teacher salary improvement. At the high school level the additional costs might be slightly less, higher intrinsic costs being offset in part because there is already some good science instruction to serve as a base in almost every part of the country.

These estimates of additional costs may be low, but not by a factor as large as 2.

Many of the Task Force recommendations to scientific societies relate to the highest priority in that set—formation of a National Council to lead in many ways the improvement of both precollege education in mathematics and science and the public understanding of science. The major scientific and technical societies could mount a likely highly effective effort through contributions aggregating $1 to $2 million annually. Oversight responsibility would have to be based on expansion of present data collection, which task is more appropriately discharged under the sponsorship of governments. We estimate that expansion would cost $3 to $5 million per year. [Both of these estimates are consistent with similar ones published by the NSB Commission.]

Since no estimate exists of the value of industry's present substantial and highly diverse contributions in support of education, there is no way to even guess at the additional expenditures which would raise industry involvement in the improvement of education to a level like that contemplated by our recommendations. It should be remembered that some of these expenditures now

are and presumably would be borne ultimately by the population at large through provision to the industry of tax incentives of different kinds. It is not ridiculous to set a primary target of 2 percent of cash flow, half of which, at least initially, should be earmarked for science and mathematics.

The leadership we recommend to the American Chemical Society does not have high additional costs; much of what we ask of the Society can be accomplished by reallocation at present levels of expenditure. The same is true for at least some of the programming we recommend to the Federal and State governments.

Estimate of costs to the people if there is not increased investment in quality education.

Public expenditures on education are determined by political processes. The participants in such processes seem interested in assuring that future increments in expenditure will buy a return that is significant and demonstrable. No one expects additional money to be "thrown at" education, even if that would accomplish the objectives desired by most of the people. Put plainly, some new contracts have to be written between the people and those whom they employ to educate their children. But, there are two parties to every contract and each of them, in this case, has some legitimate concerns about the expectations of the other. The negotiations must attend to both sets of concerns.

This is not the place to detail the matters to be negotiated. Those interested in them should start with the report of *The National Commission on Excellence in Education*, "A Nation at Risk," and then read: (1)"High School. A Report on Secondary Education in America," Ernest L. Boyer's elaboration of the work of the National High School Panel of the Carnegie Foundation, and (2) "Against Mediocrity: The Humanities in America's High Schools," a collection of essays edited by Chester E. Finn, Jr., Diane Ravitch, and Robert T. Fancher. In this triad of works aggregating 704 pages, the evidence is presented, the case made, and the issues laid out.

In comparison with cost *changes* that many of us regard as trivial in other areas of public expenditure, the *total* costs of improved education at all levels and in all areas are not staggering sums. Our estimates for the improvement of school science and mathematics total about $4 billion a year. That is a magnificent sum in the bank account of an individual, but it is round-off error in the aggregate of national and state budgets.

Educational improvement costs money. Failure to make educational improvement costs much more. Here we have estimated the costs of implementing the highest priority recommendations of the Task Force. We cannot estimate the costs associated with less than well-informed citizen judgements, continued low standards of teacher certification, obsolete instruction and teaching materials, failure to assist teachers to improve their qualifications or any of a host of consequences of inattention to the centrality of science in education for contemporary life; but those costs are surely very high.

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